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INTRODUCTION

OF THE CULTIVATED CROPS produced in Nebraska, winter wheat ranks second only to corn in importance. During the crop years of 1948-1950, the harvested winter wheat acreage averaged about 3,833,000 acres in comparison with 2,501,000 acres of oats and 7,051,000 acres of corn. The average yield of winter wheat in the state has been estimated at 19.7 bushels per acre for the seven-year period 1944 through 1950. It is well known that varietal choice, the nature of the soil, crop rotation, several cultural practices relative to land preparation, seeding and harvesting, climatic conditions, and fertilization practices have an important bearing upon yields. The effects of crop variety and cultural practices on yields have been summarized elsewhere for Nebraska (*19*). The first recorded fertilizer studies with winter wheat in Nebraska were started in 1916 by Kiesselbach and Alway at Lincoln. Further studies with commercial fertilizer for winter wheat were conducted by Russel and others in the 1920's and early 1930's (*30*), by Weldon and others in the period from 1938 to 1942 (*9, 27, 43*), and by Fitts, Hanway and others in the period from 1945 to the present time (*10, 13, 14*). Most of these fertilizer studies have been conducted in southern and western Nebraska.

It is the purpose of this bulletin to report the investigations that have been made correlating soil properties and fertilization practices with yields of winter wheat. Since the success or failure of fertilization practices is so dependent on specific soil conditions, an attempt has been made here to further characterize the major soils of the different sections of the state which are devoted to wheat production and to analyze fertilizer practices and results in relation to the soil properties determined. The data are summarized for the four sections of the state designated as southeastern, east-south-central, west-south-central and western Nebraska (Figure 1). These subdivisions have been made because of variations in soils, climate and customary soil management practices; thus, each section is reasonably uniform as to these factors.

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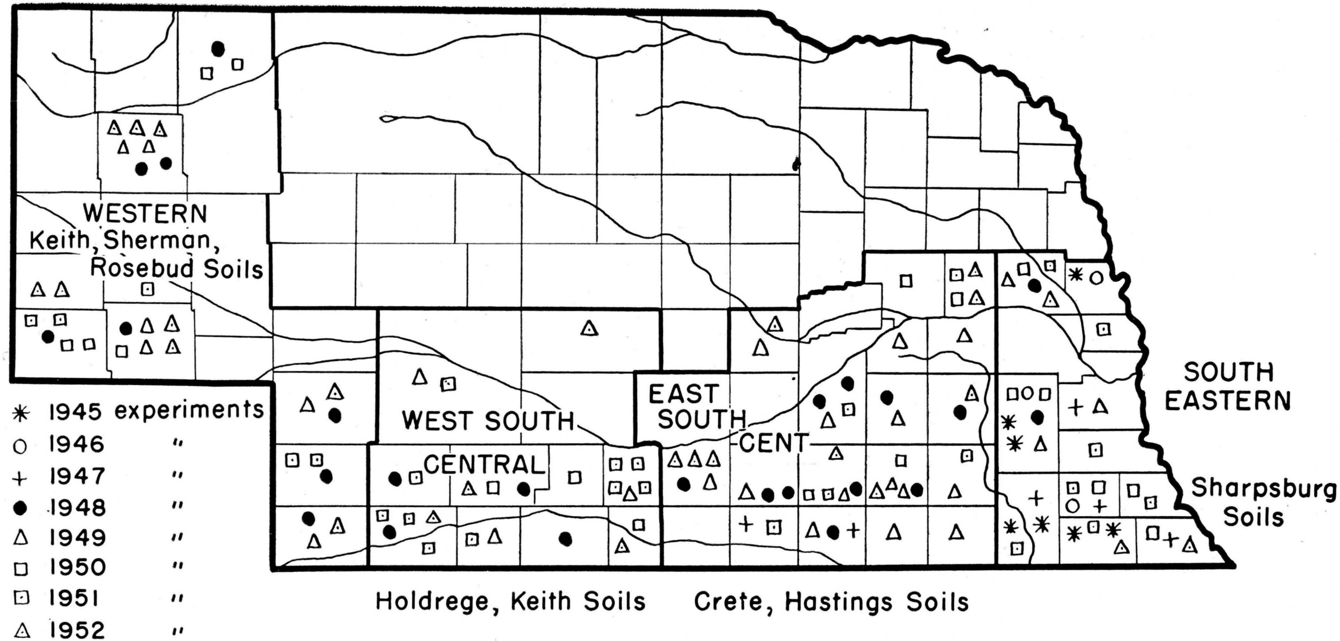

FIGURE 1.—Locations by counties of wheat experiments, 1945-1952, and subdivisions of the state according to major zonal soils devoted to wheat production.

EXPERIMENTAL METHODS

Soil samples for laboratory study were collected from sites where commercial fertilizer studies were conducted during the years 1948 to 1952. The primary objective in the location of the plots was their placement on soil areas as representative as possible of the major zonal soils growing wheat. In addition, topography and past soil management practices were considered in making selections so that the locations would be representative of the present fertility status of the major zonal soils in each section of the state. It should be emphasized that this report of soil properties and fertilizer results does not cover marginal lands of the state.

Field Methods

Most of the field experiments during recent years have been conducted by the Outstate Testing Project in cooperation with farmers and county agents.[2] From 1945 to 1947, small nursery-type plots were employed for the work, while from 1948 to 1952 the wheat was planted and fertilized with a combination grain and fertilizer drill in plots one drill width (4 or 5 feet wide) by 150 feet long. Fertilizer treatments have varied as to type and time and rate of application, although in most cases applications of nitrogen and phosphorus fertilizer alone, combinations of nitrogen and phosphorus fertilizers, and combinations of nitrogen, phosphorus and potassium fertilizers were made. Three to five replications have been used in these experiments. Figure 2 shows a general view of one of the 1950 experiments.

Soil samples were collected at each of the experimental sites in the fall prior to planting. They were obtained with a spade from the depths of 0 to 8 and 10 to 20 inches, each being a composite sample from 8 to 12 different locations within the experimental area. Laboratory studies reported have been made on these samples.

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[2] The Outstate Testing field work was carried out under the supervision of J. W. Fitts and J. J. Hanway in the years 1945 to 1947; J. J. Hanway, F. V. Pumphrey, Paul Ehlers and R. E. Luebs in 1948; R. E. Luebs and A. F. Dreier in 1949; and A. F. Dreier, G. W. Lowrey and P. L. Ehlers in 1950-52. The senior author assisted in planning the field experiments and in the interpretation of data, located plots and collected and analyzed soil samples from 1947 to 1952. Much of the work here reported was made possible by grants-in-aid with the Spencer Chemical Co., beginning in 1947, and with the Phillips Chemical Co., beginning in 1951. Additionally, fertilizer materials were provided by these companies and by the Anaconda Copper Mining Co., The Tennessee Valley Authority, Colorado Fuel & Iron Co., Mathieson Chemical Co., Farm Fertilizers Inc., and Lincoln Service & Supply Co.

FIGURE 2.—General view at two stages of crop development in one of the Outstate Testing experiments. Cass County.

Analytical Methods

Moisture equivalent of the surface soil samples was determined by the method described by Russel and Burr (*34*) with a slight modification.

Organic matter was determined by the method of Walkley and Black, as modified by Smith and Weldon (*37*).

A Macbeth pH meter was used for determining soil reaction. Readings were made on 1:2.5 suspension of soil and distilled water.

Nitrification rate of the surface soils was obtained by incubating duplicate 100-gram soil samples in pint milk bottles at moisture equivalent wetness and 25° C. temperature through a four-week period. Nitrate-nitrogen was determined at the beginning and the end of the incubation period by the phenoldisulfonic acid method (*7*) employing a Fisher electrophotometer. Nitrification rate was then derived by subtracting the initial nitrate-nitrogen content from the nitrate-nitrogen content at the end of the incubation period.

Soluble phosphorus was determined by shaking for 5 minutes a 10-gram sample of soil with 15 c.c. of one of two buffered acetic-boric acid solutions (pH 5.0 and 7.4) described by Peterson and Goodding (*28*). The solution with pH nearest the pH of the soil was used. The suspension was permitted to stand one half hour before filtering. A Klett-Summerson photoelectric colorimeter was employed for the determination.

Cation exchange capacity was determined on some of the soil samples by the ammonium acetate leaching method as described by Peterson and Goodding (*28*) with slight modifications. Potassium, calcium and sodium in the ammonium acetate leachate were determined with a Beckman flame photometer. Exchangeable magnesium was obtained by the titan yellow method essentially as described by Mehlich (*25*).

Methods described by Snedecor (*41*) were employed in determining analyses of variance and the regression analyses reported here.

CHARACTERISTICS OF THE IMPORTANT SOILS PRODUCING WHEAT IN NEBRASKA

A large amount of information is available on the soils and soil materials of Nebraska in county and state survey reports. These morphologic and geologic data have been supplemented in recent years by the determination of specific physical and chemical properties of a number of soil series (*1, 21, 22, 28, 38, 39*). Additional characterization of all of the important soil series of the state as to their physical and chemical properties is needed.

Although winter wheat is produced on 30 or more soil series in Nebraska, the greater portion of the total acreage is planted on the following seven soil series; Sharpsburg (southeastern section); Crete and Hastings (east-south-central); Holdrege (west-south-central); and Keith, Sherman and Rosebud (western). Most of the recent field studies have been conducted on soils of these series.

Description of Soils

Sharpsburg soils. These prairie soils occur extensively on the nearly level to gently undulating loess-capped upland of southeastern Nebraska. Large areas of soil originally classified and mapped as Marshall and Carrington in the old county soil surveys of southeastern Nebraska have been reclassified recently as Sharpsburg because of a higher than permissible clay content of the B horizon in the case of the former and a recognition of greater areas of loess surface mantle-rock and less glacial material at the surface in the case of the latter.

Some physical and chemical characteristics of Sharpsburg soils are presented in the appendix (Tables 28 and 29). The surface soils possess a relatively large moisture-retaining capacity due to high clay and organic matter contents. The soils are moderately to strongly acid in reaction to a depth of 20 inches or more. Liming is needed for a satisfactory production of legumes, especially alfalfa and sweetclover. Soluble phosphorus by comparison with other series investigated is rather low.

Crete soils. Extensive areas of soils belonging to this series occur in the east-south-central section of Nebraska. In the past they have been classified as "Planosols within the Chernozem region." Thorp (*42*), however, more recently has proposed a designation of "maximal" Chernozem because of the absence of a grey layer. In this region these soils have developed from Peorian loess on nearly level to gently undulating uplands. Surface and internal drainage are slow, causing difficulty in establishing crops during the spring months of years of normal or above normal rainfall. The slow internal drainage due to the fine-textured, massive subsoil is further responsible for restricted root development of crops in such years, resulting in low drouth resistance. In most cases, erosion has been slight on Crete soils.

Moderately strong acidity of the surface samples of most of the Crete soils studied is indicated by pH values ranging from 5.4 to 6.3 (Appendix, Table 28). It appears that liming might prove a profitable procedure for leguminous crops grown on Crete soil. However, that practice has received little attention on the Crete soils in east-south-central Nebraska.

Hastings soils. Soils of the Hastings series occur in extensive areas throughout south-central Nebraska. In the western portion of the region of their occurrence, for example in Kearney, Adams and Hamilton Counties, they occupy a position on the nearly level uplands, while in the eastern part of the region they occur on gently to moderately sloping positions. The parent material in all cases is Peorian loess. The designation of "medial" Chernozem proposed by Thorp appears quite fitting. The subsoil is considerably more compact and finer-textured than much of what has been mapped in the Holdrege series, but it does not approach the denseness of the Crete subsoil. Surface and internal drainage are normally adequate except in situations where the soil has been poorly managed, in which case surface crusting and runoff may be serious. For the most part, erosion has not been severe with Hastings soils other than in the eastern region of their occurrence where they occur on moderate slopes.

The Hastings soils investigated have reactions within the medium to slightly acid (pH 5.6-6.5) range, averaging about 0.3 pH unit higher than Crete samples studied (Appendix, Table 28). Mean percentage base saturation and exchangeable calcium saturation average higher than in the Crete soils (see Appendix, Table 29).

Holdrege soils. Holdrege soils occupy large areas of the nearly level to gently rolling loessial uplands in west-south-central Nebraska. These soils usually occur on the gentle slopes grading to the steep-bank canyons in this area of the state. In the past at least two different soils have been classified and mapped as Holdrege, one of which fits the designation of "medial" Chernozem by Thorp and the other "minimal" Chernozem. The former rather closely resembles Hastings soils as described except for a somewhat thinner solum, a higher lying zone of lime accumulation and a somewhat more friable subsoil. The current studies have been conducted on the soils of "medial" development. Surface and internal drainage are good, the former being excessive during intensive thundershowers which are common in this area. This has been responsible for moderate to severe erosion wherever past management of cultivated fields has not been aimed at runoff and erosion control.

The Holdrege soils are about neutral in reaction in the surface horizon, are lower in clay and organic matter contents than the previous series described, but contain relatively large amounts of soluble phosphorus.

Keith and Sherman soils. Keith soils occur on the loess-mantled tablelands of western Nebraska. They may be considered "medial" Chestnut soils. The topography ranges from nearly level in the most westerly part of the state to gently rolling in the southwestern part.

Surface and internal drainage are good; thus, water erosion is seldom a serious problem. Wind erosion is often severe, especially during the winter and spring months of dry years when cover is limited.

Sherman soils occur in intimate association with soils of the Keith series throughout western Nebraska. A dark surface layer of a buried soil in the Sherman solum serves to distinguish the series from Keith soils. The Sherman and Keith soils are regarded as ideal for dry farming because of their high inherent fertility, their relatively great depth for moisture storage, and their favorable textural and structural properties for optimum moisture penetration and storage.

The Keith and Sherman soils are neutral to slightly alkaline in reaction in the surface 20 inches, are well saturated with bases and contain large amounts of soluble phosphorus.

Rosebud soils. Rosebud soils are developed from limy Tertiary sandstones of western Nebraska. Where found in association with Keith and Sherman soils, they normally occupy the ridge tops and steeper slopes leading down to the more level loessial positions. The soil horizons are similar to those of the Keith series. The depth to bedrock naturally is quite variable, the average being about 2½ feet. Where of average depth or deeper, the soil is highly satisfactory for dry farming, but where it is much shallower the storage area for nutrients and water is inadequate. Because of the topographic position, wind and water erosion are often severe.

It is interesting to note that the initial nitrate determinations average much higher for the Keith, Sherman and Rosebud soils than for any of the other soil series. This is to be expected since most of the sites were summer fallowed and the samples were collected near the end of the fallow period when nitrate accumulation should be at a maximum. It is further significant to note that nitrification rate is of higher magnitude than would be expected from the average organic matter percentage in comparison with the other series studied. This may be attributed in part to the shorter period of time these soils have been cultivated. Also, the higher calcium saturation and perhaps better aeration of these soils probably favor nitrification.

Comparison of Soil Properties of the Different Soil Series

Increasing clay and organic matter contents of soils from west to east across the state are apparent from an observation of the mean moisture equivalent values in Table 1. Mean moisture equivalent values were 22, 24 and 28 per cent for the loam soils of western Nebraska, the silt loam soils of south-central Nebraska and the silty clay loam soils of southeastern Nebraska, respectively.

TABLE 1.—Comparison of soil properties of the different soil series studied from 1948 to 1952.[1]

Soil property	Depth, inches	South-eastern (Sharpsburg)	East-south-central (Crete)	East-south-central (Hastings)	West-south-central (Holdrege)	Western (Keith, Sherman, Rosebud)
Moisture equivalent, %	0–8	27.7	24.5	24.1	22.7	21.0
Organic matter, %	0–8	3.87	2.78	2.55	2.08	2.00
Nitrification rate, p.p.m. NO_3—N in 4 weeks	0–8	26.6	16.0	16.9	16.4	17.7
Soluble P, p.p.m. in 1½:1 extraction	0–8	0.21	0.37	0.31	0.56	0.58
pH	0–8	5.7	5.8	6.0	6.6	7.0
	10–20	5.8	6.2	6.4	7.2	7.4
Cation exchange	0–8	24.7	19.3	19.3	18.4	17.4
capacity, m.e./100 g.	10–20	29.3	26.1	21.4	23.5	20.5
Exchangeable bases,	0–8	86	89	90	94	95
% saturation	10–20	89	91	95	97	100
Exchangeable calcium,	0–8	59	61	67	63	66
% saturation	10–20	60	64	69	69	70
Exchangeable magnesium,	0–8	22	21	17	22	19
% saturation	10–20	25	21	19	25	22
Exchangeable potassium,	0–8	5.1	7.0	7.8	8.0	10.4
% saturation	10–20	3.0	4.7	6.8	4.9	8.3
Exchangeable sodium,	0–8	0.40	0.49	0.83	0.59	0.49
% saturation	10–20	0.65	0.84	0.70	0.83	0.40

[1] For complete data on individual locations see Appendix, Tables 28 and 29.

Average organic matter contents increase in zonal soils from west to east across the state as has been noted by Alway and McDole (*2*) and by Russel and McRuer (*33*) on virgin samples. The increase from west to east has been explained as resulting from higher vegetable matter production eastward, due to higher annual rainfall and lower evaporation. The organic matter content of Holdrege surface soils currently studied is somewhat low in comparison with the other series due to severe erosion and the long followed practice of summer fallowing. The average measured organic matter percentage in the western Nebraska soil types studied is appreciably higher than that in slightly coarser-textured types of the same series, other series of coarser texture, and eroded soils of the area.

It is interesting to compare the organic matter percentages with determinations which have been made previously on virgin samples from the same series across the state (Table 2). The apparent large organic matter losses with all of the series investigated affords explanation of why nitrogen has become the chief limiting factor in crop production in Nebraska as far as soil fertility is concerned. That loss of organic matter in soil has a distinct bearing on yields of crops has been demonstrated by Russel (*32*) in a study with two contiguous

TABLE 2.—Organic matter contents of surface soils obtained in this study compared with organic matter contents of virgin soils of the same series reported by other investigators.

Section of state	Soil series	Organic matter content of virgin samples, %[1]	Organic matter content of samples obtained in this study, %	Organic matter loss, %[2]
Southeastern	Sharpsburg (formerly called Marshall)	5.20	3.95	24
East-south-central	Crete and Hastings (much of which was formerly called Grundy and Holdrege)	4.55	2.69	41
West-south-central	Holdrege	3.40	2.12	38
Western	Keith, Sherman, Rosebud (formerly called Rosebud)	2.90	2.06	29

[1] Compiled from numerous organic matter determinations of top soils of the series presented by Alway and McDole (*2*), Russel and McRuer (*33*), Russel and Weldon (*35*), and in unpublished data.

[2] Based on the assumption that the soils of the experimental sites originally had organic matter contents equal to those of the virgin soils of similar types.

fields in Lancaster County, both cultivated about 40 years. One of these fields through mismanagement had been reduced in organic matter content to 1.60 per cent (a loss of 69 per cent), while the other field, which was better managed, contained 3.66 per cent organic matter (29 per cent loss). These two fields were prepared similarly for wheat in the fall of 1927. Determinations to a depth of 3 feet in the following April showed 10.6 pounds and 64.5 pounds of nitrate-nitrogen per acre, respectively, in the two fields. The respective grain yields were 7.5 and 26.6 bushels per acre.

The relatively greater organic matter losses of soils of south-central Nebraska in comparison with Sharpsburg soils of eastern Nebraska can probably be attributed to the less favorable average moisture conditions for and consequent limited use of grasses, legumes and other green manure crops in the rotation for organic matter maintenance. Perhaps the smaller losses in western Nebraska are due to the fact that the soils have not been cultivated as long as in the central and eastern parts of the state.

Russel stated as early as 1929 (*32*) that "one of the most important phases of the organic matter problem in the dry-land region is a thorough study of the possibilities of nitrogen fertilizer. Such study should, of course, be conducted over a period of years to include both wet and dry seasons, particularly on lands already depleted to the point where nitrogen is limited and always with the point in mind of eliminating the hazards of overstimulation. In the meantime, it is highly important that all the reputed virtues of organic matter be submitted to rigorous tests. Should it transpire that the physical values of organic matter have been overemphasized and that nitrogen can be maintained . . . . through the use of fertilizers, the way is clear for continued development of dry-land agriculture along its present lines of power farming and extensive grain production." The danger of overstimulation from nitrogen fertilizer use is no longer considered serious as long as proper fertilization methods are employed. Furthermore, recent data suggest that organic matter and yields can be maintained through nitrogen fertilization and proper crop residue management (*29, 40*). With increasing availability of nitrogenous fertilizer materials and decreasing cost for the nitrogen it would appear that Russel's early suggestion may materialize in the relatively near future.

Nitrification rate was relatively low for all of the soil series in south-central and western Nebraska. In western Nebraska soils, the average nitrification rate is not sufficiently high to explain the large yields of wheat normally obtained on summer fallowed land. However, the large amount of nitrate accumulated during the summer fallow period contributes to supplying adequate amounts of nitrogen. This accumulation of available nitrogen in the soil through summer fallowing is apparent from an observation of the "Initial nitrate" column in Table 28, Appendix.

Soluble phosphorus in the 0- to 8-inch samples was determined with the same reagents and procedures as used in the Soil Testing Laboratory. This was done to obtain further correlation between soil testing measurements and field results from phosphorus fertilizer application. Average determinations for each of the soil series indicate a gradual increase in available phosphorus westward across the state.

An increase in pH values of the zonal soils from east to west across the state was accompanied by an increase in base saturation. Cation exchange capacity values decreased from east to west as did organic matter and clay contents of the soils, while percentage base saturation and exchangeable calcium saturation increased.

Exchangeable magnesium was uniformly high in all of the soil series studied. Magnesium saturation of the exchange complex averaged about 20 per cent for all series, and the exchangeable calcium:magnesium ratio is about 3 to 1 in all sections.

Exchangeable potassium was higher in the 0- to 8-inch depth than in the 10- to 20-inch depth almost without exception, and relatively high with all series. The lowest percentage potassium saturation was noted with the most acid Sharpsburg and Crete soils. If exchangeable potassium may be considered largely available for plant growth, it is apparent that even the Sharpsburg and Crete soils are high in available potassium, the average of these determinations indicating about 1900 pounds K_2O per acre surface foot. It is not surprising that no consistently favorable results have been obtained from potassium fertilization of crops grown on zonal soils of Nebraska.

Exchangeable sodium was quite low, averaging less than 1 per cent saturation in all series.

These data show that the soil series studied, as they are differentiated and mapped on the basis of characteristics which are apparent in the field, also are distinctly different in their chemical and physical properties measured in the laboratory. Furthermore, the data suggest that differences in response of crops to applications of commercial fertilizer should obtain on the different series.

NITROGEN FERTILIZERS FOR WINTER WHEAT

Numerous studies have been carried out in the past throughout the United States and in other countries relative to methods for supplying the wheat crop with additional quantities of nitrogen. In general, the crop has been responsive to fertilization with most kinds of nitrogenous materials where grown on soils of moderate to low fertility wherever moisture was not too serious a limiting factor for crop production.

It is well known that certain practices of land preparation have an important bearing on yields of wheat due to their influence on nitrification in soils. Despite the fact that moisture has generally received the greatest attention in respect to wheat production throughout most of the drier sections of the country, including Nebraska, many farmers and investigators have recognized that nitrogen often may be a greater limiting factor than moisture. Call (*4*) in eastern Kansas, for example, observed in 1914 that early plowing in that area was of value in obtaining high wheat yields because of an improved nitrogen relationship. He concluded that the higher yields obtained from early tillage could be attributed to the greater liberation of nitrogen rather than to additional moisture storage. Sewell and Call (*36*) made a similar deduction in 1925, noting that the wheat land studied which was plowed in July contained 20 p.p.m. more nitrate-nitrogen and yielded 9 bushels per acre more wheat than land prepared in September.

Kiesselbach and Lyness (*19*) pointed out that higher yields of wheat following July 15 plowing as compared with September 15 plowing at Lincoln were due in part to moisture conservation and in part to higher nitrate production in the early plowed soil. In these studies, October nitrate-nitrogen contents were approximately four times as much in the plots plowed July 15 as in the plots plowed

September 15, two and one half times as much in the following April, and twice as much immediately following harvest. They further found that greater increases in yield due to early plowing were obtained with a soil of moderate fertility than with a soil of relatively high fertility, suggesting that more than a moisture conservation factor was involved.

Farmers of western Nebraska have come to recognize that more than moisture storage is required in that area where summer fallowing is extensively practiced. It is well known there that "stubble" wheat will not yield as much as fallowed wheat even in years when moisture is plentiful. Thus, it appears that a lack of adequate nitrogen in the soil is one of the problems.

Legumes in the rotation are highly effective for maintaining an adequate supply of available nitrogen in the soil for the wheat crop in those climatic regions where moisture is not likely to be deficient. As a general rule, only the eastern counties and irrigated sections of Nebraska are supplied with enough moisture throughout the season to justify growth of biennial or perennial legumes for this specific purpose using conventional methods of farming. It should be mentioned, however, that excellent results have been obtained with biennial legumes in south-central Nebraska where used in a stubble-mulch system of farming. It is further believed by some that certain annual legumes such as partridge pea with a lower water requirement might be employed with the subtillage system and projected even farther westward in the state. Even so, for much of the wheat producing area of the state, other ways must be devised for supplying the crop with nitrogen.

Nitrogen Absorption by Winter Wheat

In a study of the nitrate factor in wheat production at Lincoln, Jones (*18*) observed three different stages of nitrogen absorption. The first stage, between germination and the following mid-March, may account for 5 to 50 per cent of the total nitrogen taken up, depending upon the amount of fall growth as governed by fall temperature, moisture, time of planting and soil fertility. The second period, between resumption of growth in the spring and heading, together with the first period, may account for as much as 80 per cent of the total nitrogen assimilated by the plants. This period also coincides with that of greatest dry matter production, but the maximum weight of dry matter normally is not achieved until approximately two weeks after the maximum nitrogen accumulation in the crop. The third stage, between the time of heading and harvest, accounts for up to 20 per cent of the total nitrogen utilized, depending upon

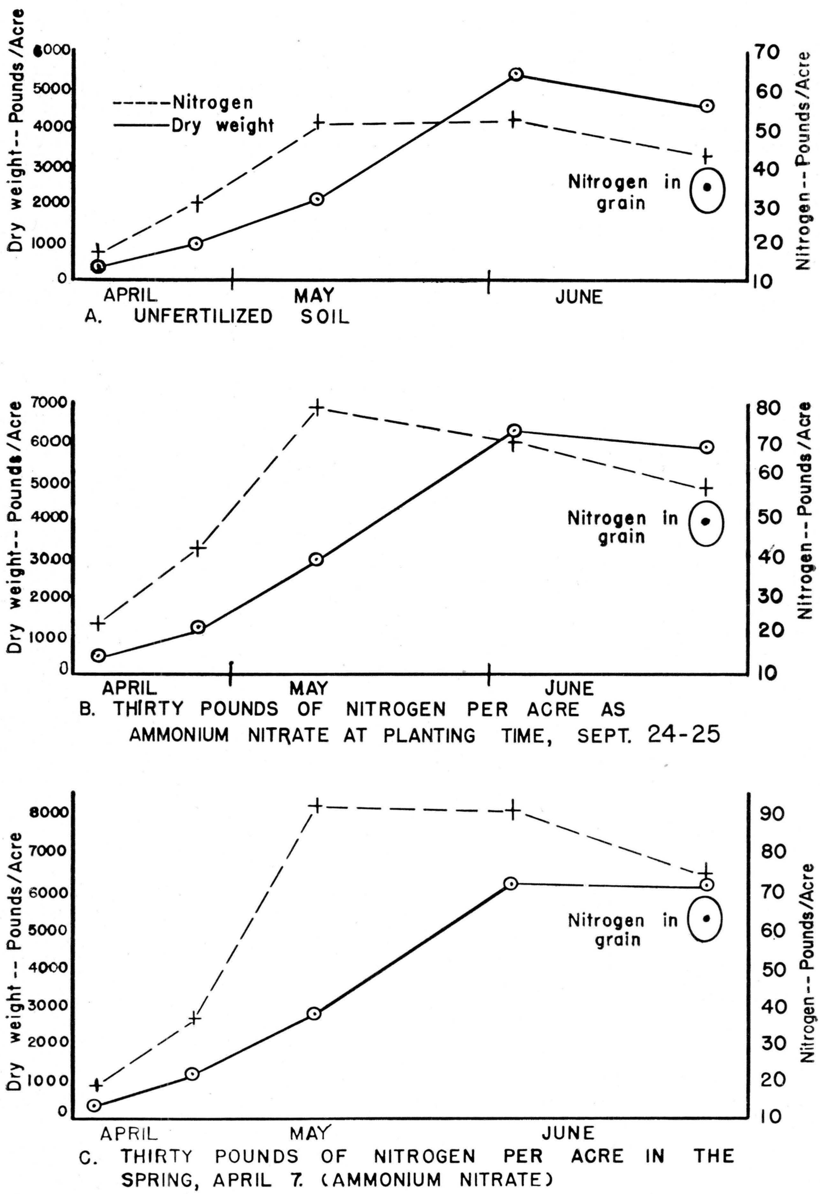


FIGURE 3.—Comparison of above-ground dry weights and nitrogen contents of winter wheat at different stages of growth. Mean of two experiments. Lancaster County, 1948.

the factors of moisture, soil fertility and temperature. It is in this five to six weeks' period that one fourth to as much as three fourths of the nitrogen previously accumulated in the leaves and stems of the plants is translocated to the grain. Although the nitrogen content of the grain normally increases from formation to maturity, in cases where nitrogen assimilation is limited during the first two stages and the soil is low in available nitrogen during the last stage a decline in protein content is noted with maturity of the grain.

Johnson *et al.* (*17*) determined the dry weight and nitrogen content of the above-ground portions of winter wheat in two experiments conducted in Lancaster County during 1948 to compare the effects of different nitrogen carriers. Mean results from the two experiments for the unfertilized wheat, the wheat receiving 30 pounds nitrogen per acre as ammonium nitrate at planting time and 30 pounds nitrogen per acre as ammonium nitrate in the spring are presented in Figure 3. The maximum rate of nitrogen assimilation by the wheat on the unfertilized soil was during the period from April 15 to May 10 and most of the nitrogen was in the plant by May 10. The period of maximum rate of vegetative increase was somewhat later than the period of maximum nitrogen accumulation with the maximum dry weight being obtained about June 4. The decline in total weight and total nitrogen content after June 4 apparently resulted from falling leaves and bloom.

The period of most rapid vegetative growth in 1948 was earlier where supplemental nitrogen was applied either in the fall or spring than where no fertilizer was applied. The period of maximum nitrogen assimilation, however, was from April 26 to May 10 regardless of the time of nitrogen treatment. The rates of assimilation for the periods April 13 to April 26 and April 26 to May 10 were not greatly different where nitrogen fertilizer was not applied, and both were much slower than where nitrogen fertilizer was applied. A maximum accumulation of nitrogen in the plants and ultimately in the grain resulted from the spring application of ammonium nitrate. As noted in the June 26 sampling, 38 pounds of nitrogen per acre was in the grain from the check plots, 51 pounds in the grain from the plots fertilized in the fall, and 62 pounds in the grain from the plots receiving a spring application of nitrogen fertilizer.

According to the data in Figure 3, a large part of the nitrogen required by the wheat crop can be utilized during the second stage of growth, described by Jones, between the resumption of growth in the spring and heading. It is believed that this fact is of importance. It means that much of the supplementary nitrogen needed for the wheat crop can be supplied in the spring. Thus, in the case of highly soluble nitrate salts the hazards of leaching, microbiological tie-up and denitrification are reduced as compared with a planting-time application. Also it permits an evaluation of stand and moisture conditions relatively late in the crop season before estimating the feasibility of nitrogen fertilization. It should be pointed out, however, that a certain amount of available nitrogen must be present in the soil for the early establishment of the crop.

Increase in Yield of Winter Wheat Due to Nitrogen Fertilizer

The earliest known record of fertilizer studies with wheat in Nebraska is unpublished data of the Nebraska Agricultural Experiment Station of 1916-1920. These data were obtained in a three-year rotation of corn, oats and wheat at Lincoln by Kiesselbach and Alway. As an average for the five-year period, an annual application of 2½ tons of manure per acre increased the grain yield 1.6 bushels per acre; the same amount of manure with lime caused an increase of 3.1 bushels per acre; and a combination of dried blood, bone meal and potassium chloride supplying 34, 56 and 36 pounds of N, P_2O_5 and K_2O, respectively, per acre increased the yield 2.3 bushels per acre. By comparison with the above fertilizer results, the application of 2 tons straw per acre increased the average acre yield 1.9 bushels.

In 1921 Russel conducted fertilizer investigations at six locations on Hall soils in Hall County (*31*). Well rotted barnyard manure applied at the rate of "five loads per acre" was the most effective fertilizer used, the mean increase in yield being 5.2 bushels per acre. "Acid" phosphate was ineffective (0.9 bushel per acre increase) as was 200 pounds of a 2-8-2 fertilizer (2.2 bushels per acre increase). The same treatments were employed at five locations in Hall County during 1922 with even poorer results than those obtained in 1921, probably because of dry weather. In 1923, experiments including similar treatments were conducted in Washington and Gage Counties, and an additional treatment of sodium nitrate was added. Mean increases of 3.6 and 2.8 bushels per acre were noted in the three Washington County tests for applications of the 2-8-2 and sodium nitrate fertilizer, respectively. Corresponding mean increases for the two Gage County tests were 2.6 and 4.7 bushels per acre.

Jones (*18*) reported rather consistent yield increases from nitrogen fertilizer applications on the Agronomy Farm at Lincoln during 1924. Best results were obtained from early spring applications. Protein content of the grain produced was noted to increase as the soil nitrate supply increased.

Russel *et al.* (*30*) reported that the response of winter wheat to applications of commercial fertilizers on Sharpsburg silty clay loam differed appreciably from year to year. In the 16-year period of the experiment (1921-1936) there was a total of five years showing no response of wheat to fertilizer, seven years showing a noticeable increase in yield due to phosphate fertilizer alone, and four years showing a response of wheat to both nitrogen and phosphorus fertilizer. As an average for the 16-year period, there was no benefit from the use of a nitrogen fertilizer (Table 3). There was, however, a noticeable benefit from the nitrogen fertilization in four of the 16 years. It seems likely that the slight response of wheat to applications of nitrogen fertilizer during the period 1921-36 compared with the present was due in part to the small rates of nitrogen employed, in part to the general reduction in organic matter and nitrogen level of the soil since then, and in part to the more favorable climatic conditions during recent years. The alfalfa included in the rotation also probably had a confounding effect on the nitrogen treatments.

TABLE 3.—Influence of commercial fertilizer on yields of winter wheat on Sharpsburg silty clay loam.[1] Lincoln, Nebraska. (Summarized from unpublished data of Lyness, Kiesselbach, Anderson, Russel, and Weldon.)

Fert. applied, lbs./a. of $N-P_2O_5-K_2O$	Mean yields in bushels per acre for different periods					Mean yields for 4 yrs. when increases in yield due to N fertilizer were noted, bu./a.[2]
	1921-24	1925-28	1929-32	1933-36	1921-36	
0 — 0—0	37.3	24.5	35.9	20.0	29.4	28.0
13 — 0—0	39.9	26.9	38.1	16.8	30.4	32.0
0 —16—0	39.5	23.9	42.9	23.5	32.4	34.1
0 —16—4	39.5	25.8	40.9	24.8	32.7	31.1
3.3—16—4	40.5	24.3	40.9	23.5	32.2	32.8
6.6—16—4	36.9	25.5	42.6	22.9	31.9	32.9
13 —16—4	41.1	24.4	43.7	22.4	32.6	35.2
26 —16—4	39.4	24.1	43.2	20.3	31.7	36.9

[1] Results obtained in a 16-year rotation of alfalfa four years with corn, oats and wheat rotated for a period of 12 years.

[2] Years of 1923, 1929, 1932 and 1936 that showed some response to nitrogen fertilizer as well as phosphorus fertilizer.

Russel *et al.* (*30*) studied different types of nitrogen fertilizer for wheat in eastern Nebraska during 1928 and 1929. They noted consistent and appreciable increases in yield of wheat from spring top-dressings of 40 pounds of nitrogen per acre as sodium nitrate. They reported an average increase in 1928 on eight fields in eastern Nebraska of 8.2 bushels per acre from that treatment, and in 1929 on eleven fields the increase averaged 8.4 bushels per acre. None of the eight experiments conducted in central Nebraska during 1929 showed yield response from 40 pounds of nitrogen, the average increase for all of the locations being 0.5 bushel per acre. Signs of nitrogen deficiency were noted in the nontreated plots and early response in vegetative growth from nitrogen fertilizer appeared promising, but summer drouth eliminated the advantage of the fertilizer.

TABLE 4.—Response of winter wheat in Nebraska to applications of nitrogen, phosphorus and potassium fertilizer. 1946-1952.

Year	Number of experiments	Yield without fertilizer, bu./acre	Increases in yield, bu./acre due to[1]			
			N	P	N+P	N+P+K
		Southeastern Nebraska				
1946	3	28.9	4.6	1.1	9.3	9.0
1947	4	25.0	5.9	–0.8	5.6	4.7
1948	1	22.9	12.5	1.3	19.6	17.7
1949	1	20.3	2.5	6.6	12.6	11.5
1950	4	28.8	8.0	1.8	14.3	13.2
1951	5	7.7	1.4	2.3	6.0	5.3
1952	3	25.7	3.3	1.0	7.0	8.3
Mean 21 experiments		21.9	4.8	1.1	9.1	8.6
		East-south-central Nebraska				
1947	2	14.4	13.4	–1.8	11.5	7.2
1948	7	28.8	10.7	–0.1	11.5	13.7
1949	8	14.2	6.4	0.5	7.4	7.4
1950	4	22.3	10.1	0.4	13.1	12.3
1951	5	11.0	3.5	0.4	6.1	5.9
1952	5	22.2	4.6	....	6.4	8.0
Mean 31 experiments		19.3	7.5	0.2	8.9	9.3
		West-south-central Nebraska				
1948	4	44.3	4.3	–0.7	3.4	6.9
1949	2	15.5	1.4	0.8	1.9	0.3
1950	2	32.5	6.5	1.2	5.0	7.3
1951	2	22.6	4.6	....	3.2	4.5
1952	4	24.8	–0.5	–0.5	–0.8	–0.5
Mean 14 experiments		29.9	2.9	0.1	2.2	3.6
		Western Nebraska				
1948	6	42.5	0.5	1.1	0.6	2.0
1949	3	23.2	–1.4	2.6	0.1	2.0
	2	24.8[2]	11.2	....	11.2	....
1950	2	20.9	1.2	2.7	1.7	0.9
	2	3.5[2]	2.8	....	2.8	....
1951	2	30.2	8.0	....	8.3	5.3
	2	2.0[2]	0.1	....	0.7	....
1952	6	20.2	–2.0	2.2	–1.3	–1.0
	2	7.8[2]	0.5	......	1.6	....
Mean 19 experiments[3]		28.8	0.3	1.9	0.9	1.3
Mean of the 4 regions		25.0	3.9	0.8	5.3	5.7

[1] Nitrogen applied as ammonium nitrate at the rate of 40 pounds per acre in the spring. Phosphorus was applied as superphosphate at the rate of 30 pounds P_2O_5 per acre with the seed at planting. Potassium was applied as potassium chloride at the rate of 30 pounds K_2O per acre with the seed at planting.

[2] Box Butte Experiment Farm.

[3] Experiments from Box Butte Experiment Farm omitted in means.

Results reported by Fitts *et al.* (*10*) and Hanway *et al.* (*13, 14*) throughout the state are comparable to those obtained by Russel *et al.* in eastern Nebraska. Table 4 summarizes the recent results for the various sections of the state, and emphasizes the greater state-wide need for nitrogen fertilizer supplements than for phosphorus and potassium fertilizers. Increases in yields of wheat due to an application of 40 pounds of nitrogen per acre alone averaged 4.8, 7.5 and 2.9 bushels per acre in southeastern, east-south-central and west-south-central Nebraska, respectively. The average increase in yield for western Nebraska where most of the plots were summer fallowed was only 0.3 bushel per acre. It is apparent that the nitrogen fertility problem decreases in magnitude from east to west in the state. Regarding the latter dry farming area of the state, many questions exist as to most effective soil management practices for wheat production. Research projects currently underway at the Box Butte Experiment Farm and the North Platte Experiment Station in which methods of residue management and tillage, fertilizer treatments, and different planting dates are being evaluated should eventually supply many of the answers.

Rate of Nitrogen Fertilizer

Yield and protein content of the grain are influenced by the rate of nitrogen fertilizer applied. In most experiments noticeably larger yields of wheat have been obtained from an application of 40 pounds of nitrogen than from an application of 20 pounds per acre (Tables 5 and 6). Furthermore, the protein content of the grain has generally been higher with the larger application of nitrogen (Table 6). An application of 60 pounds of nitrogen per acre has not generally

TABLE 5.—Comparison of two rates of fertilizer, 20 and 40 pounds nitrogen per acre, applied for winter wheat in eastern Nebraska during 1946 and 1947.[1]

Location	Number of experiments	Yield with phosphate fertilizer only, bu./acre	Increase in yield, bu./acre, due to rate of N applied[2]	
			20 lbs. N/acre	40 lbs. N/acre
	1946			
Southeastern	3	30.0	4.7	7.8
	1947			
Southeastern	4	24.2	4.6	6.4
East-south-central	2	12.6	8.3	14.3
	Mean			
	9	23.6	5.5	8.6

[1] Calculated from data reported by Hanway *et al.* (*13*). All plots received 30 pounds P_2O_5 as superphosphate applied with the seed at planting.
[2] Ammonium nitrate applied as a top-dressing in the spring.

been superior to either 40- or 30-pound rates for increasing yields of grain (Tables 6 and 7). In contrast, increases in protein percentage of grain have been materially larger with the 60-pound rate of nitrogen than with lower rates. These results indicate that 30 or 40 pounds of nitrogen per acre is the optimum rate for increasing yields of grain on the average zonal soils of Nebraska. However, if the farmer obtains a premium for increased protein content of grain, a larger rate of nitrogen may be warranted. The maximum practical rate of nitrogen for increasing protein is problematical. An interesting observation was made inadvertently in this respect, however, in Nebraska during 1950 with five experiments where approximately 100 pounds nitrogen per acre caused 14.5 per cent protein wheat as compared with 11.8 per cent protein wheat for the 40-pound rate. Two of these experiments included a 60-pound nitrogen treatment which caused 12.1 per cent protein wheat as compared with 14.9 per cent protein where the 100-pound rate was applied.

Many farmers recently have taken advantage of the demand and premium paid for quality wheat, individually or through elevator

TABLE 6.—Comparison of 20, 40, and 60 pounds nitrogen per acre applied as ammonium nitrate in the spring for the production of winter wheat. Experiments throughout Nebraska during 1950-1952.[1]

Year	Number of experiments	Check	Increase due to rate of nitrogen applied, pounds per acre[2]		
			20	40	60
		Yield, bushels per acre			
1950	6	24.5	2.1	8.5	8.8
1951	10	14.1	2.8	4.0	4.4
1952[3]	4	25.5	3.5	7.3	8.8
Mean for 3 years		21.4	2.8	6.6	7.3
		Protein content, per cent			
1950	6	11.3	0.4	1.3	2.0
1951	10	11.1	0.3	0.6	0.9
1952	4	9.7	-0.1	1.0	1.6
Mean for 3 years		10.7	0.2	1.0	1.5
		Recovery of applied nitrogen in grain, per cent[4]			
1950	6	......	18	37	29
1951	10	......	16	12	9
1952	4	......	12	24	20
Mean for 3 years		......	15	24	19

[1] 1950 was a good wheat year in which marked response to nitrogenous fertilizer obtained; the reverse was true in 1951. In much of the state good wheat yields were obtained in 1952, although locally drouth damage was severe.

[2] Most plots received 30 to 45 pounds P_2O_5 as superphosphate applied with the seed at planting. Yield and protein figures are on 14 per cent moisture basis.

[3] Data from several western Nebraska experiments omitted due to conflicting results brought about by hot, dry weather during the heading stage. In general for the western experiments cited, progressively smaller yields accompanied increased rate of nitrogen application.

[4] Based on the differences in nitrogen content of wheat without nitrogen fertilizer and that receiving the designated amounts of nitrogen.

TABLE 7.—Influence of time and rate of applying ammonium nitrate on yields of winter wheat in eastern Nebraska. 1948.[1]

Time of applying nitrogen fertilizer	Rate of ammonium nitrate, pounds nitrogen per acre 0	30	60	Mean increase due to 30 and 60 pounds N/acre treatments
	Yield, bushels per acre			
Fall	35.8	45.6	51.6	12.8
Winter	35.8	45.5	47.4	10.6
Spring	35.8	49.2	50.8	14.2
Mean increase	......	11.0	14.1	......
	Protein content, per cent			
Fall	8.6	9.1	10.0	1.0
Winter	8.6	9.1	9.5	0.7
Spring	8.6	10.3	11.5	2.3
Mean increase	....	0.9	1.7	....
	Recovery of applied nitrogen in the grain, per cent			
Fall	....	37	36	36
Winter	....	36	25	30
Spring	....	69	48	58
Mean	....	47	36	....

[1] Values are means of results from two locations. Yield and protein figures on 14 per cent moisture basis.

operators. Many others producing high protein grain in quantity should avail themselves of this possible additional income to make their farming operation more profitable.

A limited number of experiments and many observations indicate that an application of 30 or 40 pounds nitrogen may not be optimum for wheat production on soils that are highly deficient in nitrogen during years of adequate or more than adequate rainfall. The following data obtained from two experiments on eroded soils in southeastern Nebraska during 1950 illustrate that something over 40 pounds of nitrogen per acre may be needed under those conditions:

Lbs. N applied per acre	*Time of application*	*Yield, bu./acre*
0	....	8.7
40	Spring	15.1
80	Spring	18.3
120	Spring	18.9
160	Spring	14.8
320	½ spring, ½ heading	14.6

Little lodging was evident with the high rates of nitrogen employed; yield depression with the highest rates apparently resulted from accentuated weed competition (Figure 4).

On fields that are only moderately low in nitrogen, lodging of the grain may result from a large application of nitrogen fertilizer (Fig-

FIGURE 4.—Eighty pounds of nitrogen per acre applied to this eroded field caused a marked yield increase. An application of 320 pounds nitrogen per acre, however, was less effective because of extreme competition from weeds.

ure 5). The phenomenon is the result of a low carbohydrate-nitrogen ratio usually due to excessive available nitrogen which favors rank leaf and stalk growth. The rank growth, because of increased shading, causes the development of succulent and weak stalks which cannot stand the beating action of rain and wind. If the plants are knocked down after heads have formed they will not stand up again. This results in low yields because of undeveloped kernels and grain that cannot be recovered. The danger of lodging has been recognized by farmers in the past on their most fertile soils, especially after alfalfa or heavy manure application. The development of stiffer-strawed varieties of wheat such as Pawnee, Nebred and Cheyenne has alleviated this hazard, but the possibility of lodging still cannot be overlooked. Although rates of nitrogen up to 60 pounds per acre have produced little or no lodging in the experiments conducted throughout the state recently, it is probable that nitrogen applied at rates as low as 40 pounds per acre to soils already high in available nitrogen could cause the grain to lodge. Much more nitrogen than needed also may induce a weed problem. In other words, it is important to adjust the rate of nitrogen applied to the nitrogen status of the soil.

Where wheat is a companion crop for a clover or alfalfa seeding, an application of more than 20 pounds of nitrogen per acre has frequently been responsible for reduced stands and limited growth of the legume. The stimulated vegetative growth of the wheat in these cases has caused excessive shading of and excessive nutrient

FIGURE 5.—Lodging in center was caused by an application of approximately 100 pounds N per acre to a soil of moderately high fertility. No lodging was apparent on left or right where 40 pounds N per acre was applied.

FIGURE 6.—In very wet years nitrogen fertilizer applied at relatively high rates to wheat may prove beneficial to a concurrent clover seeding. In normal years on most soils, moderate rates of nitrogen fertilizer will reduce the new legume stand. Otoe County, 1951.

and moisture competition with the legume seedlings. In some years of above normal moisture, however, as in eastern Nebraska during 1951, the newly seeded clover or alfalfa may be stimulated markedly by rather high rates of nitrogen fertilizer (Figure 6).

Time of Applying Nitrogen Fertilizer

Fitts *et al.* (*10*) reported that a spring application of nitrogen fertilizer was generally more effective than a fall application for winter wheat on several soils of southeastern Nebraska during 1945. At two locations on Sharpsburg soils and two locations on soils developed from glacial material, the most profitable fertilizer practice was an application of phosphate at planting time followed by a nitrogen supplement in the spring. In these studies only 20 pounds of nitrogen per acre was applied, and according to the authors, "it seemed likely that the amount of nitrogen applied was insufficient to give maximum benefits." Similar results were obtained in 1946 and 1947 (Table 8).

TABLE 8.—Comparative effects of fall and spring application of 20 pounds of nitrogen as ammonium nitrate on the yield of winter wheat. Experiments in eastern Nebraska. 1945-1947.[1]

Year	Number of experiments	Phosphate fertilizer only, bu./acre	Increase in yield, bu./acre, due to time of applying nitrogen fertilizer	
			Fall	Spring
1945	7	29.3	1.9	6.9
1946	3	30.0	3.8	4.7
1947	6	20.4	3.7	5.8
Mean for three years		26.6	3.1	5.8

[1] All plots received 30 pounds P_2O_5 as superphosphate with the seed at planting.

Where 40 pounds of nitrogen per acre was applied in 1948-1952, there was little difference in effectiveness of fall, spring or split applications (Table 9). However, these methods of application were superior to the winter application in the one year where the latter method was studied. The reduced effectiveness of a winter application can probably be attributed to removal of some of the fertilizer by runoff with melting snow or spring rain where the soil was frozen. It was apparent in several of the 1949 experiments that 20 or more pounds of nitrogen per acre as fertilizer placed with the seed may have a deleterious effect on the crop by reducing stands if drouthy conditions exist after planting. This hazard is not encountered where the fertilizer is placed other than in direct contact with the seed.

Spring applications of nitrogen fertilizer should not be delayed beyond the middle of April in most years. Late May and June applications do not cause optimum yield increases and may result in excessive weed competition (Figure 7).

TABLE 9.—Comparison of fall, winter, spring, and split applications of 40 pounds of nitrogen for winter wheat in Nebraska. 1948-1952.[1]

Location	Number of experiments	Yield with phosphate fertilizer only, bu./acre	Increase in yield, bu./acre, due to time of applying nitrogen fertilizer			
			Fall	Winter[2]	Spring	Split[3]
		1948				
Southeastern	1	24.2	11.7	10.5	18.3	14.8
	2[4]	35.7	12.9	10.7	13.7	.....
East-south-central	7	28.7	12.5	10.2	11.6	12.3
West-south-central	4	43.6	4.8	3.7	4.6	6.6
Western	6	41.5	1.4	0.9	1.5	2.3
Mean 18 experiments		36.0	7.0	5.7	7.1	7.8
		1949				
Southeastern	1	26.9	4.5	....	6.0	7.4
East-south-central	7	14.3	7.1	....	7.3	7.1
Western	2	27.0	0.0	....	–0.2	–0.1
Mean 10 experiments		18.1	5.4	....	5.7	5.7
		1950				
Southeastern	2	30.4	11.5	....	15.7	13.7
East-south-central	3	23.0	14.6	....	12.0	12.1
West-south-central	2	33.7	6.6	....	3.8	9.0
Western	2	22.1	1.0	....	0.5	0.9
Mean 9 experiments		26.8	9.1	....	9.1	9.3
		1951				
Southeastern	3	9.0	5.3	....	1.7	4.7
East-south-central	4	13.0	7.5	....	5.2	5.8
West-south-central	1	25.2	1.6	....	2.0	3.6
Western	3	25.3	2.0	....	5.3	6.0
Mean 11 experiments		16.4	4.9	....	4.0	5.4
		1952				
Southeastern	3	25.7	7.3	....	6.7	7.3
East-south-central	1	27.0	11.0	....	11.0	12.0
Mean 4 experiments		26.0	8.2	....	7.8	8.5
Mean for five years		24.7	6.9	....	6.7	7.3

[1] All plots received 30 pounds P_2O_5 per acre as superphosphate applied with the seed at planting. Ammonium nitrate was applied at the rate of 40 pounds nitrogen per acre.
[2] Applied early in December.
[3] 10 pounds nitrogen applied in fall and 30 pounds nitrogen in spring.
[4] Average values from 30 and 60 pounds nitrogen per acre treatments.

Although the results presented in Table 9 do not indicate a special advantage for a split application of nitrogen fertilizer, it seems probable that such a practice should be followed on soils of very low fertility where it is difficult to obtain stands and adequate fall growth. Furthermore, in those areas where both phosphorus and nitrogen are deficient, a low nitrogen-high phosphorus mixed fertilizer supplemented by additional nitrogen in the spring can be used to advantage.

Despite the fact that similar increases in yield of grain accrued from spring and fall applications of nitrogen fertilizer during 1948-52, spring applications were superior to either fall or winter applications

FIGURE 7.—Eighty pounds nitrogen per acre applied on April 1 (left) proved much more effective for increasing yield than the same amount applied on June 1 (right). Otoe County, 1951.

for raising protein content (Table 10). Thus total nitrogen recovery was considerably greater with the spring treatment than with the fall or winter treatments (Table 11).

Recent work measuring the persistence of the ammonium ion in soil and its deleterious effect on soil structure (*11*) raises further question as to the practice of broadcasting ammonium salts on the soil in the fall and winter months. The detriment is especially marked on clayey soils of low organic matter content when environmental conditions prevent rapid nitrification of the ammonium ion.

In addition to the fact that a spring application of nitrogen fertilizer is usually more efficient than a fall application, the factor of moisture availability should be considered. Since moisture is often a limiting factor in crop production in much of Nebraska, it is to the farmer's advantage to make the latest possible appraisal of the moisture situation prior to fertilizer application. Thus if fall, winter and early spring moisture storage has been appreciable, fertilizing in April (at 3- to 6-inch growth stage) should be a good risk; if not, saving the fertilizer for another crop or another year is probably in order. Furthermore, leaching losses of the spring-applied fertilizer are not likely to be as severe as with a fall treatment in years of plentiful moisture. It should be noted, however, that observations made in Nebraska in recent years indicate that crops growing on

TABLE 10.—Relation of time of application of nitrogen fertilizer to the protein content of winter wheat in Nebraska. 1948-1952.[1]

Location	No. of experiments	Protein content with phosphate fertilizer only, %	Increase in protein content, %, due to time of applying nitrogen fertilizer: Fall	Winter[2]	Spring	Split[3]
			1948			
Southeastern	1	10.4	0.0	0.5	1.5	1.5
East-south-central	7	11.2	1.0	1.0	1.6	0.6
West-south-central	4	11.2	1.7	1.6	2.9	2.3
Western	6	11.7	1.6	1.9	2.6	2.4
Mean 18 experiments		11.3	1.3	1.4	2.3	1.6
			1949			
Southeastern	1	10.2	0.6	....	1.4	1.4
East-south-central	7	11.2	–0.3	....	–0.2	0.0
Western	2	10.6	1.5	....	1.3	0.8
Mean 10 experiments		11.0	0.2	....	0.3	0.3
			1950			
Southeastern	2	10.8	0.0	....	1.7	0.1
East-south-central	3	10.4	0.2	....	1.2	0.5
West-south-central	2	10.3	1.3	....	2.3	1.7
Western	2	15.7	1.3	....	0.8	0.9
Mean 9 experiments		11.6	0.8	....	1.5	0.8
			1951			
Southeastern	3	11.3	0.1	....	0.1	0.0
East-south-central	4	11.2	–0.3	....	–0.1	–0.1
West-south-central	1	13.0	0.9	....	0.4	0.2
Western	3	10.8	0.7	....	1.2	1.0
Mean 11 experiments		11.3	0.2	....	0.4	0.3
			1952			
Southeastern	3	10.3	0.1	....	0.9	0.5
East-south-central	1	11.0	0.9	....	1.0	0.6
Mean 4 experiments		10.5	0.3	....	0.9	0.5
Mean for five years		11.1	0.6	....	1.1	0.7

[1] All plots received 30 pounds P_2O_5 per acre as superphosphate applied with the seed at planting. Ammonium nitrate was applied at the rate of 40 pounds nitrogen per acre.
[2] Applied early in December.
[3] 10 pounds nitrogen applied in fall and 30 pounds nitrogen in spring.

soils of low nitrogen level are likely to suffer greater damage from moderately drouthy conditions than the same crops grown on soils of high nitrogen level. This is apparently a result of root stimulation by nitrogen and utilization of a deep-lying supply of soil moisture when present. There may be occasions when a spring application does not have an appreciable effect on yields due to top-dressing on a dry surface soil with no rain to carry the fertilizer into the soil until after the period of high nitrogen requirement by the wheat.

TABLE 11.—Relation of time of application of nitrogen fertilizer to the percentage nitrogen recovery by winter wheat in Nebraska. 1948-1952.[1]

Location	Number of experiments	Percentage of the 40 pounds nitrogen applied that was recovered in the grain			
		Fall	Winter[2]	Spring	Split[3]
		1948			
Southeastern	1	32	33	67	56
East-south-central	7	48	40	51	43
West-south-central	4	35	31	50	50
Western	6	22	24	34	35
Mean 18 experiments		36	32	46	43
		1949			
Southeastern	1	17	....	28	32
East-south-central	7	19	....	20	21
Western	2	10	....	8	5
Mean 10 experiments		17	....	18	19
		1950			
Southeastern	2	33	....	65	40
East-south-central	3	41	....	50	37
West-south-central	2	31	....	33	43
Western	2	7	....	7	9
Mean 9 experiments		29	....	40	33
		1951			
Southeastern	3	13	....	4	12
East-south-central	4	17	....	13	14
West-south-central	1	10	....	8	11
Western	3	8	....	20	21
Mean 11 experiments		13	....	12	15
		1952			
Southeastern	3	21	....	26	24
East-south-central	1	41	....	42	41
Mean 4 experiments		26	....	30	28
Mean for five years		24	....	29	28

[1] All plots received 30 pounds P_2O_5 per acre as superphosphate applied with the seed at planting. Ammonium nitrate was applied at the rate of 40 pounds nitrogen per acre.
[2] Applied early in December.
[3] 10 pounds nitrogen applied in fall and 30 pounds nitrogen in spring.

Effectiveness of Different Nitrogen Carriers for Wheat

Hutchinson and Miller (*16*), growing wheat in sterile sand cultures, observed that the plants absorbed nitrogen in ammonium form just as readily as in the nitrate form, and under some conditions developed a higher percentage nitrogen content where ammonium nitrogen was used. They further noted that other nitrogen compounds as amides, simple amino acids and urea may be absorbed directly.

Russel *et al.* (*30*) studied different nitrogen carriers as top-dressings in eastern Nebraska during 1928 and 1929. In 1928, applications of 40 pounds nitrogen as ammonium sulfate and sodium nitrate were included in eight experiments, and calurea was included in one of these experiments. Mean increases in yield were 8.2 and 2.0 bushels per acre for sodium nitrate and ammonium sulfate, respectively. The range for sodium nitrate was from an increase of 15.9 bushels per acre to a decrease of 2.4 bushels per acre; the range of increase for ammonium sulfate was from 5.1 to 0.7 bushels per acre. Calurea was slightly more effective than sodium nitrate in the one experiment where it was used. In 1929, sodium nitrate and calurea were equally effective and superior to ammonium sulfate as spring top-dressings for wheat. As a mean of nine experiments, sodium nitrate increased the yield of winter wheat by 8.1 bushels per acre and ammonium sulfate increased yields 6.0 bushels per acre.

On the average, ammonium sulfate has been nearly as effective for top-dressing winter wheat in the spring as ammonium nitrate during the period 1948 to 1952 (Tables 12, 13, 14). However, in some experiments ammonium sulfate was distinctly inferior to ammonium nitrate. The latter result occurred when the surface 1 to 3 inches of soil was dry at and following application of the fertilizers. Presumably, there was adequate moisture for the absorption of the ammonium nitrogen by the soil at the immediate surface but inadequate amounts to cause nitrification of the ammonium form to the nitrate form or to allow roots to develop. Apparently where moisture conditions are favorable for nitrification of the ammonium nitrogen, thereby permitting downward movement of nitrate, or adequate for the growth of plant roots in the immediate surface of the soil, the two forms of nitrogen are equally effective. Maximum difference between ammonium sulfate and ammonium nitrate should occur during years when there is little spring moisture and the surface of the soil remains dry for long periods of time. Urea was equivalent or slightly superior to ammonium nitrate as a spring top-dressing for winter wheat in the four-year comparison. Data from these and other experiments not reported here indicate that fall broadcasting of urea on the surface frequently results in nitrogen losses beyond those encountered with other carriers. Cyanamid was definitely inferior to the other three nitrogen carriers studied.

Some work in Nebraska indicates that nitrogen solutions are comparable to dry ammonium nitrate and anhydrous ammonia for wheat as long as an equal number of pounds of nitrogen per acre is applied (*17*). It seems reasonable that those solution products containing urea and/or ammonium nitrate as the basic carrier(s) should function in a similar manner to their dry counterparts. Unpublished data from two years' work indicate that concentrated solutions of this type should be used as a soil applicant in the fall or

TABLE 12.—Comparison of ammonium nitrate, ammonium sulfate, calcium cyanamid and urea applied at the rate of 40 pounds of nitrogen per acre as a top-dressing in the spring. Nebraska, 1948-1952.

Location	No. of experiments	Yield without nitrogen fertilizer, bu./acre	Increase in yield, bu./acre, due to nitrogen fertilizer			
			Ammonium nitrate	Ammonium sulfate	Cyanamid	Urea
		1948[1]				
Southeastern	1	22.9	12.5	8.5	....	....
East-south-central	7	28.8	10.7	7.3	....	....
West-south-central	4	44.3	4.3	3.6	....	....
Western	6	42.5	0.5	1.7	....	....
Mean 18 experiments		36.5	6.0	4.7	....	....
		1949[1]				
Southeastern	1	20.3	2.5	2.2	–1.5	....
	1	30.8	0.1	3.5	–1.2	3.0
East-south-central	8	14.2	6.4	5.0	3.9	....
West-south-central	2	15.5	1.4	1.7	1.0	....
Western	3	23.2	–1.4	0.5	2.4	....
Mean 15 experiments		17.7	3.5	3.4	2.5	....
		1950[2]				
Southeastern	4	30.9	12.8	11.9	7.6	....
	2	31.4	10.0	7.2	8.1	9.1
East-south-central	3	23.2	13.8	10.1	5.7	....
West-south-central	2	33.6	3.9	6.1	2.6	4.9
Western	1	24.6	–0.8	–0.8	0.1	–0.9
Mean 12 experiments		29.0	10.0	8.6	5.7	....
		1951[2]				
Southeastern	1	5.5	3.8	3.7	4.1	5.0
East-south-central	3	13.5	5.5	8.2	3.2	12.4
West-south-central	1	25.2	1.8	3.8	2.8	2.8
Western	3	25.3	6.4	5.0	4.4	6.0
Mean 8 experiments		18.4	5.2	5.9	3.7	7.9
		1952[2]				
Southeastern	2	34.0	6.5	6.5	5.0	7.0
East-south-central	3	22.3	8.0	6.3	6.3	6.7
Mean 5 experiments		26.0	7.4	6.4	5.8	6.8
		Mean for five years				
Mean 58 experiments		26.6	6.2	5.5	....	....
Mean 40 experiments		22.2	6.4	....	4.1	....
Mean 19 experiments		24.4	5.6	....	....	6.7

[1] No phosphate applied.
[2] All plots received 30 pounds P_2O_5 per acre at planting time.

early spring rather than as a foliar application on wheat late in the season for effecting maximum yield increases. It has been noted that under some conditions the concentrated solutions are more difficult to apply than other materials.

Seven experiments were conducted in eastern Nebraska from 1948 to 1952 comparing ammonium nitrate and anhydrous ammonia for winter wheat (Table 15). It is evident from these data that anhydrous

TABLE 13.—Comparison of the effects of ammonium nitrate, ammonium sulfate, calcium cyanamid and urea applied at the rate of 40 pounds nitrogen per acre in the spring on the protein content of wheat. Nebraska, 1948-1952.

Location	No. of experiments	Protein content without nitrogen fertilizer, %	Increase in protein content, %, due to nitrogen fertilizer			
			Ammonium nitrate	Ammonium sulfate	Cyanamid	Urea
		1948[1]				
Southeastern	1	10.7	1.6	0.0	....	....
East-south-central	7	11.5	1.7	1.2	....	....
West-south-central	4	11.3	2.6	0.6	....	....
Western	6	12.0	2.6	1.1	....	....
Mean 18 experiments		11.6	2.2	1.0	....	....
		1949[1]				
Southeastern	1	11.6	1.4	1.6	1.8	....
	1	10.8	0.0	0.6	0.4	0.8
East-south-central	8	11.1	–0.1	0.3	–0.4	....
West-south-central	2	12.1	0.7	1.5	0.8	....
Western	3	11.0	2.0	2.9	0.7	....
Mean 15 experiments		11.2	0.5	1.0	0.2	....
		1950[2]				
Southeastern	4	10.5	1.5	1.5	0.5	....
	2	10.7	0.9	0.8	0.6	1.0
East-south-central	3	10.4	1.1	1.0	0.1	....
West-south-central	2	10.3	2.3	1.0	0.1	0.8
Western	1	14.5	1.9	1.4	0.1	1.7
Mean 12 experiments		10.8	1.5	1.2	0.3	....
		1951[2]				
Southeastern	1	10.9	–0.9	–0.7	–0.7	–0.7
East-south-central	3	11.3	–0.1	0.0	–0.2	0.3
West-south-central	1	13.0	0.4	1.6	0.1	1.3
Western	3	10.8	0.9	0.9	1.0	0.3
Mean 8 experiments		11.3	0.2	0.4	0.2	0.3
		1952[2]				
Southeastern	2	10.2	0.4	0.4	0.0	0.4
East-south-central	3	10.9	0.8	1.0	0.4	0.5
Mean 5 experiments		10.6	0.6	0.7	0.2	0.5
		Mean for five years				
Mean 58 experiments		11.2	1.2	1.0	....	....
Mean 40 experiments		11.0	0.8	....	0.2	....
Mean 19 experiments		11.1	0.7	....	....	0.6

[1] No phosphate applied.
[2] All plots received 30 pounds P_2O_5 per acre at planting time.

ammonia applied 4 to 5 inches deep prior to planting in the fall or in the early spring is fully as effective as ammonium nitrate applied in the spring.

Effect of Nitrogen Fertilizer on Test Weight of Wheat

Some investigators have related fertilizer practices to test weight of wheat. From observations made to date in Nebraska on this sub-

TABLE 14.—Percentage of nitrogen recovered by wheat from ammonium nitrate, ammonium sulfate, calcium cyanamid and urea applied in the spring at the rate of 40 pounds nitrogen per acre. Nebraska, 1948-1952.

Location	No. of experiments	Percentage of the 40 pounds nitrogen applied that was recovered in the grain			
		Ammonium nitrate	Ammonium sulfate	Calcium cyanamid	Urea
		1948[1]			
Southeastern	1	50	24	....	....
East-south-central	7	50	34	....	....
West-south-central	4	46	18	....	....
Western	6	31	18	....	....
Mean 18 experiments		43	25	....	....
		1949[1]			
Southeastern	1	16	16	4	....
	1	0	15	0	16
East-south-central	8	18	15	9	....
West-south-central	2	7	12	7	....
Western	3	7	20	12	....
Mean 15 experiments		13	16	8	....
		1950[2]			
Southeastern	1	52	49	26	....
	2	38	28	29	36
East-south-central	8	48	36	16	....
West-south-central	2	33	27	8	21
Western	1	9	6	1	7
Mean 12 experiments		42	35	19	....
		1951[2]			
Southeastern	1	7	7	8	10
East-south-central	3	13	20	7	39
West-south-central	1	7	14	7	22
Western	3	21	18	17	16
Mean 8 experiments		15	17	11	25
		Mean for five years			
Mean 58 experiments		30	24	....	....
Mean 40 experiments		23	..	13	
Mean 19 experiments		21	...	..	24

[1] No phosphate applied.
[2] All plots received 30 pounds P_2O_5 per acre at planting time.

ject, it would appear that nitrogen fertilization has a slight depressing effect on test weight (see Table 21, p. 47).

Relation of Soil Properties to the Need for Nitrogen by Wheat

Consistent increases in yield of winter wheat due to the application of nitrogen fertilizer have been obtained on Sharpsburg, Crete, Hastings and Holdrege soils. Less consistent increases were obtained on Keith, Rosebud and Sherman soils (Table 16). It is believed that the results reflect the present nitrogen status of the most important soils growing wheat under average management practices. Where a

TABLE 15.—Comparison of ammonium nitrate and anhydrous ammonia applied to winter wheat in eastern Nebraska.

Nitrogen carrier[1]	Time of application	Mean increase in yield, bu./acre	Mean increase in protein content, %	Mean recovery of nitrogen applied, %
		1948[2]		
Ammonium nitrate	September	12.8	1.0	37
Anhydrous ammonia	September	14.9	1.7	50
Ammonium nitrate	April	13.7	2.3	54
		1949[3]		
Ammonium nitrate	September	2.3	0.3	10
Anhydrous ammonia	September	3.0	0.6	15
Ammonium nitrate	April	2.0	0.0	7
Anhydrous ammonia	April	–3.5	1.6	1
		1950[4]		
Ammonium nitrate	August	5.4	0.4	21
Anhydrous ammonia	August	7.7	0.9	36
Ammonium nitrate	September	4.3	0.0	11
Anhydrous ammonia	September	8.8	0.6	32
Ammonium nitrate	April	8.6	1.3	36
		1952[5]		
Anhydrous ammonia	September	11.0	–0.1	23
Anhydrous ammonia	April	10.5	0.7	27
Ammonium nitrate	April	13.5	0.7	34
		Mean for four years		
Anhydrous ammonia	September	10.4	0.7	30
Ammonium nitrate	April	10.5	1.1	33

[1] All plots received 45 lbs. P_2O_5 with the seed at planting time.
[2] Mean of 30 and 60 pounds nitrogen per acre. Two experiments on Sharpsburg silty clay loam. Average yield of grain without nitrogen fertilizer was 35.8 bu./acre with 8.6 per cent protein.
[3] Mean of 20, 40, and 60 pounds nitrogen per acre. One experiment on Sharpsburg silty clay loam. Yield of grain without nitrogen fertilizer was 30.8 bu./acre with 10.8 per cent protein.
[4] Mean of 20, 40 and 60 pounds nitrogen per acre. Two experiments on Sharpsburg silty clay loam. Mean yield of grain without nitrogen fertilizer was 31.4 bu./acre with 10.4 per cent protein.
[5] Fifty pounds nitrogen per acre. Two experiments on Crete silty clay loam. Average yield of grain without nitrogen fertilizer was 22 bu./acre with 10.1 per cent protein.

greater use is made of legumes in the cropping system and/or manure applications than normal, increases in yield of wheat due to nitrogen fertilizer should be less. On the other hand, larger increases in yield of wheat due to nitrogen fertilizer may be expected on the associated sandy or eroded soils where the organic matter and nitrogen contents of the soils are decidedly lower than in the soils studied here.

Differences in response of winter wheat to applications of nitrogen fertilizer are related to the management practices followed in the different areas (e.g., fallow prior to wheat on most of the Holdrege, Keith, Sherman and Rosebud soils studied), length of time the land has been cultivated, and the availability of moisture during the growing season. Nitrate-nitrogen as well as moisture accumulates under

TABLE 16.—Effect of 40 pounds of nitrogen applied as ammonium nitrate in the spring on the yield of winter wheat grown on the major zonal soils of Nebraska. 1946-1951.

Year	Number of experiments	Yield of check plots, bu./acre	Increase in yield due to 40 lbs. of nitrogen, bu./acre
	SHARPSBURG		
1946	3	28.9	4.6
1947	3	22.7	6.4
1948	1	19.5	13.8
1949	1	20.3	6.0
1950	5	32.2	10.2
1951	1	14.8	6.1
Mean		26.0	8.2
	CRETE		
1947	3	17.3	12.5
1948	3	33.2	6.7
1949	5	14.1	6.6
1950	2	17.5	11.6
1951	2	15.3	3.6
Mean		19.2	8.1
	HASTINGS		
1947	1	20.5	9.9
1948	4	25.6	13.8
1949	4	15.0	6.6
1950	1	35.7	14.1
1951	2	10.5	4.3
Mean		20.0	9.5
	HOLDREGE		
1947	1	23.3	11.5
1948	4	38.8	7.7
1950	3	31.8	5.5
1951	6	17.5	3.7
Mean		27.1	5.8
	KEITH, ROSEBUD AND SHERMAN		
1947	2	22.6	6.4
1948	7	43.6	2.4
1949	4	17.1	3.5
1950	3	12.3	2.9
1951	2	30.2	7.5
Mean		28.7	3.7

fallow so that an appreciable quantity of available nitrogen may be present in fallowed soils at the time wheat is planted. In general, the Keith, Sherman and Rosebud soils of western Nebraska have not been cultivated as long as the soils in the other parts of the state. Furthermore, the moisture supply is often more limiting in western Nebraska than in other areas even though fallowing prior to wheat is practiced. For these reasons, nitrogen response has been less in the western soils than in those of eastern Nebraska. It should be recognized, however, that because of the use of fallow in western

Nebraska along with the initially lower organic matter and nitrogen contents of the soils it is especially important that the problem of nitrogen maintenance in those soils be considered.

Soil series designation alone is not adequate for specifying the probable need for nitrogen by crops in making maximum yields, largely because differences exist in the past management history and degree of accelerated erosion with different tracts. A reliable soil test which would evaluate the soil's nitrogen status is needed. Any test which determines the momentary ammonium- or nitrate-nitrogen content of the soil is probably valueless in view of the rapid fluctuations of these materials in soils with changes in environment. In this study, the amount of nitrate-nitrogen in the soil just prior to planting was compared with check yields of wheat and with yield increases from nitrogen fertilization. No correlation was apparent.

Some studies indicate that the nitrification rate of the soil may be used to determine the need of a given crop for additional nitrogen when grown on similar soils where the climatic factor is nearly constant. Hanway (*12*) obtained a significant positive correlation between nitrification rate of the soil and corn yields in the rotation experiment at Lincoln. Black *et al.* (*3*) in Iowa found that a direct relationship existed between "mineralizable soil nitrogen" and wheat yields. In the current study, yields of wheat on rotation plots of the Agronomy Farm at Lincoln were compared with nitrification rate of the soil in those plots. The results plotted in Figure 8 suggest a close relationship between the nitrification rate and wheat yields for the crop years 1950 and 1951, the correlation coefficients being +.708 and +.701, respectively. The two curves are decidedly different, which is to be expected in view of the extreme climatic differences between the two years. Moisture and temperature conditions were near optimum for wheat growth in 1950, which resulted in excellent yields. In 1951, however, excessive moisture with incident plant diseases restricted yields.

The above observations indicate nitrification rate is a valid measure of soils' capacity to deliver nitrogen to a crop in a given locale of slight climatic and soil variation. At this point the question naturally arises as to the regional or state-wide application of the test. Can the test be meaningful when applied over the entire state of Nebraska with the wide range of soil conditions that exist, and especially in view of the extreme range of 16 to 34 inches annual rainfall? In Figure 9, nitrification rate is plotted against check yields of continuously cropped outstate locations for the five years 1948-1952. Apparently the test is valid for specifying the nitrogen status of the soil in terms of crop needs over a wide range of soil and climatic conditions.

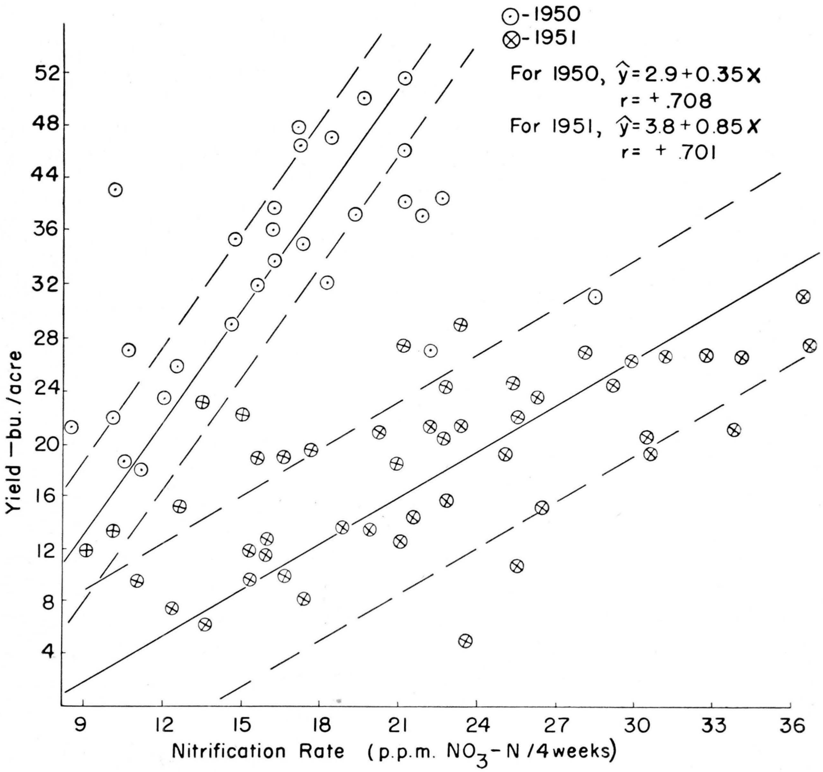


FIGURE 8.—Relation between nitrification rate of soil and yield of wheat on Agronomy Farm rotation plots. Lincoln, 1950-51.

Nitrification rate is related to yield increase due to nitrogen fertilizer in Figure 10. The increase plotted represents increase as percentage of the maximum yield in order to iron out some of the variation due to climate. The highly significant correlation noted (Table 17) is further evidence of the value of nitrification rate for specifying the nitrogen status of a soil. The data suggest that substantial yield increases are likely from nitrogen fertilization when the soil's nitrification rate is below 20 p.p.m. per four weeks.

In the case of wheat after fallow, nitrification rate appears to be of little value for predicting nitrogen supplement needs. The compounded effects of frequent high yields without fertilization in the summer fallow region, extremely variable yields due to spotty rainfall in the semiarid climate, and the two-year nitrate supply accumulated with the summer fallow practice apparently invalidate the test.

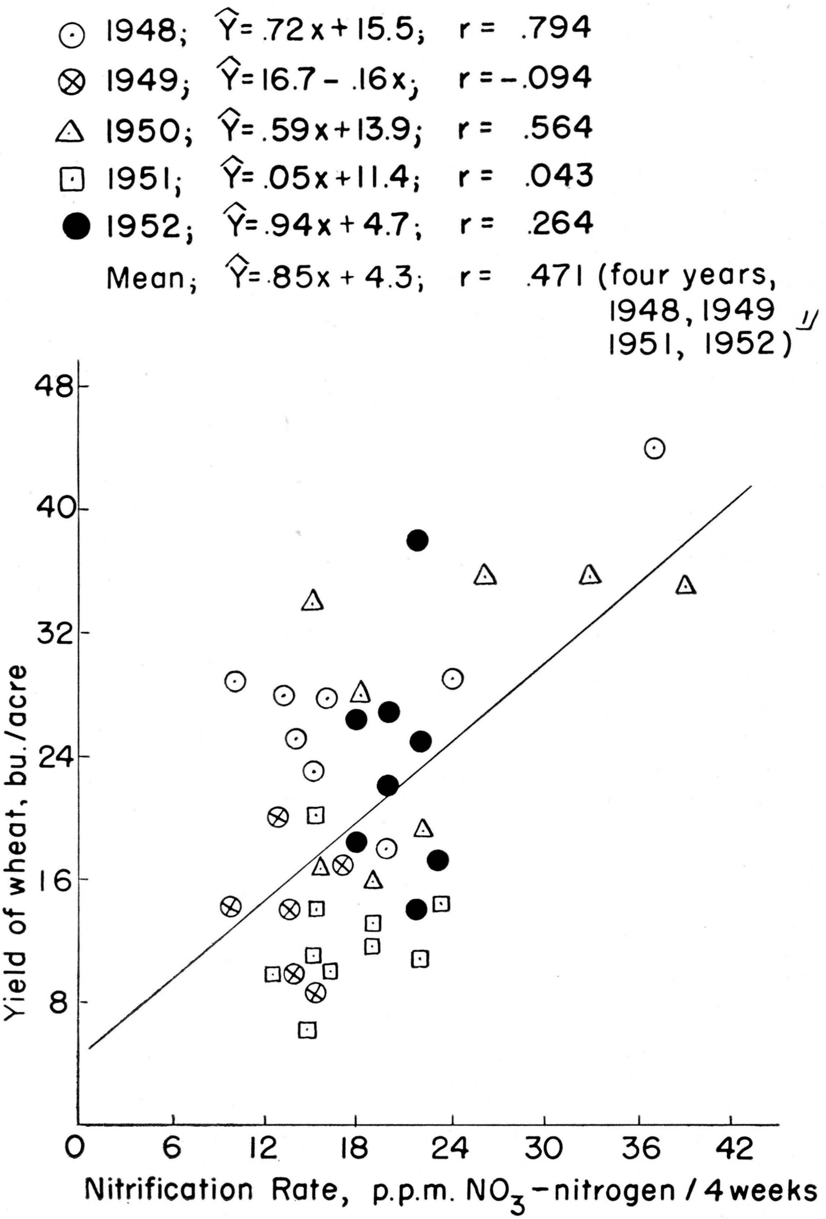


FIGURE 9.—The relation between nitrification rate of soil and check yield of wheat in Nebraska experiments, 1948-1952.

[1] See footnote of Table 17.

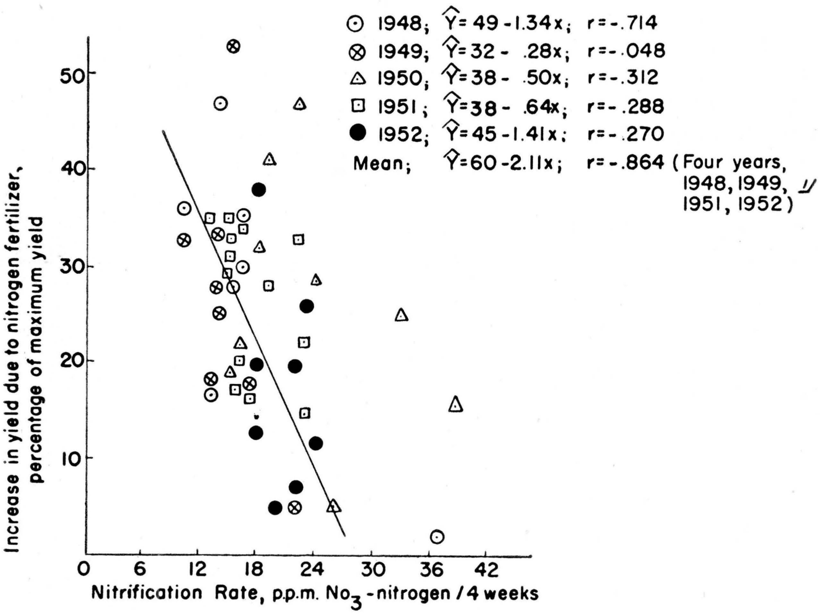


FIGURE 10.—Yield increases of winter wheat from 40 pounds of nitrogen per acre in the spring as percentage of the maximum yield plotted against nitrification rate. Nebraska experiments, 1948-1952.

TABLE 17.—Comparison of nitrification rate and organic matter percentage for estimating the nitrogen status of Nebraska soils for the production of winter wheat. Data from the four years 1948, 1949, 1951 and 1952.[1]

Correlation	Correlation coefficient (r)	
	Nitrification rate	Organic matter, percentage
Wheat after small grain (38 comparisons)		
Yield, bushels per acre	.471**	.349*
Yield, percentage of maximum yield	.498**	.112
Increase in yield due to N fertilizer, bu./A	–.457**	–.152
Increase in yield due to N fertilizer, percentage of maximum yield	–.864**	–.292
Wheat after fallow (27 comparisons)		
Yield, bushels per acre	–.152	–.003
Yield, percentage of maximum yield	.106	.161
Increase in yield due to N fertilizer, bu./A	–.201	–.085
Increase in yield due to N fertilizer, percentage of maximum yield	–.208	.009

** Significant at the 1% level, highly significant.
* Significant at the 5% level, significant.
[1] Few organic matter measurements were made in 1950, thus comparisons are impossible for that year.

The relationship between nitrification rate and yield response to nitrogen fertilization is undoubtedly curvilinear, and there is an indication of this in the data presented. It is anticipated, however, that a linear or near linear relationship will generally be found to exist within the range of nitrification rates where *profitable* yield increases are obtained from nitrogen fertilization.

In view of these observations, it is believed that nitrification rate might well be considered for a testing procedure of the Soil Testing Laboratory for continuously cropped soils. The procedure

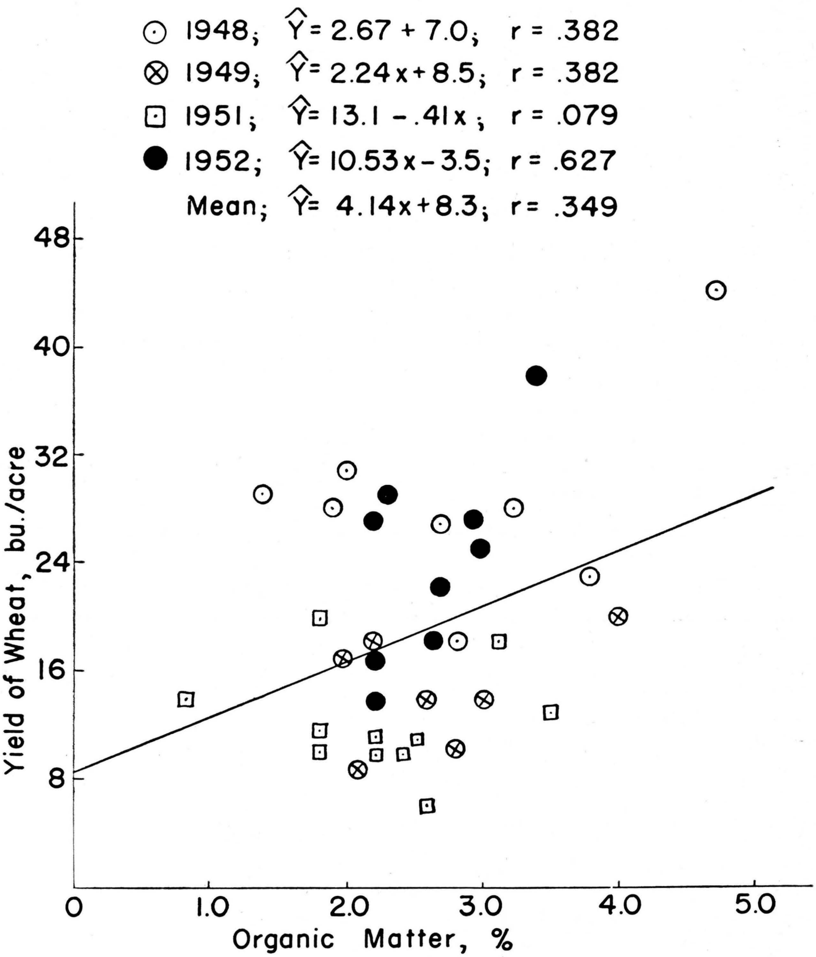


FIGURE 11.—The relation between organic matter content of soil and check yield of wheat in Nebraska experiments, 1948-1952.

need not be so time-consuming as that employed in this investigation. Landrau (*20*) has demonstrated that nitrification rates determined over a two-week period are completely in accord with those over a month or two-month period.

Other investigators have suggested that the soil's organic matter content may be used as a criterion for predicting yields of crops grown on the soil and for predicting the need for supplemental nitrogen. This contention is borne out by correlations determined between wheat yields on rotation plots of the Agronomy Farm in 1950 and organic matter content and nitrification rate of the soil. Correlation coefficients were highly significant in both comparisons and were of approximately equal magnitude. This observation, however, applies to one small area of uniform soil and climatic conditions. When the comparison between organic matter content and nitrification rate is expanded to cover all soils studied throughout the state, the latter is a much more valid measurement for specifying nitrogen status of soil (Table 17 and Figure 11).

PHOSPHORUS FERTILIZERS FOR WINTER WHEAT

In much of the United States and the world, phosphorus is the key element to the problem of soil fertility. This is especially true of the more humid regions where soils are strongly acid in reaction. The soils of semiarid to subhumid regions, however, are generally higher in available phosphorus than those of the humid regions. The latter applies to much of Nebraska, and it is not likely that phosphorus fertilizers will be needed on many soils of the state for some time.

Absorption of Phosphorus by Winter Wheat

Phosphorus is absorbed by plants largely as orthophosphate compounds, more readily as the monophosphate ion (H_2PO_4-), somewhat less readily as the diphosphate ion ($HPO_4^=$), and least readily as the trivalent ion ($PO_4\equiv$) (*24*). Thus in the production of superphosphate much of the phosphorus is converted to the readily available monophosphate ion. Metaphosphate and pyrophosphate compounds in fertilizer apparently are absorbed directly but are converted to orthophosphates before utilization by plants. Organic forms of phosphorus in soils are converted to orthophosphates prior to absorption and utilization. Several investigations have shown that from one third to one half of the total phosphorus in the surface horizon of zonal soils is contained in the soil organic matter. Furthermore, the organic phosphorus compounds are readilv mineralized, releasing available phosphorus to growing crops. Thus, those soils that are high in organic matter in a given area are not likely to be as deficient in phosphorus as similar soils low in organic matter.

Yield Increases of Winter Wheat Due to Application of a Phosphorus Fertilizer

Russel (*31*) reported results with the use of phosphate fertilizer for winter wheat in central Nebraska on Hall soils during 1921 and 1922. As an average of the 11 experiments conducted in those two years, "acid phosphate" at the rate of 100 pounds per acre had little or no effect on yield when applied singly. There was an apparent depressing effect from the phosphate when it was applied in conjunction with manure, for the plots receiving both manure and phosphate were lower in yield than those treated with manure alone.

Almost identical results were obtained in 1923 on three farms in Washington County as in central Nebraska in 1921 and 1922, i.e., no response from "acid phosphate" alone and a depressing effect of the phosphate where it was included with a manurial treatment. With three experiments of the same type in Gage County, however, the phosphorus treatment alone provided an average yield increase of 2.4 bushels per acre and where included with manure caused yields averaging 3.3 bushels higher than the individual manure applications.

In 1933, Russel *et al.* (*30*) summarized phosphorus fertilizer results with wheat in a rotation experiment on Sharpsburg soil at the Agronomy Farm for the period 1921-1932 (Table 18). A biennial fertilizer application of 32 pounds P_2O_5 per acre[3] in the rotation was noted to have increased yields of wheat an average of about 3 bushels per acre for the 12-year period, with a range from plus 11.2 to minus 3.8 bushels per acre. An application of twice this amount of phosphorus every four years, or the same average annual rate, was less effective. During the interval of this study there were four years of no response to fertilizer, five years of good response to phosphorus fertilizer, and three years of greatest response to a fertilizer containing nitrogen and phosphorus. As an average of the "phosphorus years," increments of nitrogen above a basic treatment of 100 pounds 0-16-4 fertilizer per acre had little effect on yields, and successive 100-pound increments of 3.3-16-4 fertilizer up to 48 pounds of P_2O_5 per acre caused yield increases of 4.9, 8.0, and 9.3 bushels per acre, respectively. In the three "nitrogen-phosphorus years," successive increments of 3.3-16-4 up to a 10-48-12 application resulted in yield increases of 3.7, 6.4 and 9.0 bushels per acre, respectively. In these three years 13 pounds of nitrogen per acre alone increased the yield 5.6 bushels per acre (Table 18).

[3] In this and later expressions of amounts of phosphorus fertilizer applied, pounds of P_2O_5 means pounds of available phosphorus expressed as P_2O_5.

TABLE 18.—Increase in yields of wheat from commercial fertilizer on Sharpsburg silty clay loam at Lincoln during the 12-year period 1921-1932 (summarized from unpublished data of Kiesselbach, Russel, Anderson and Lyness). Fertilizers applied at planting time.[1]

Treatment $N-P_2O_5-K_2O$, lbs./acre	Four "No response years"	Three "Nitrogen-phosphorus years"	Five "Phosphorus years"	Mean of twelve years
	Yield of check plots (bu./acre)			
0— 0— 0	28.3	27.2	36.5	31.4
	Increase due to fertilizer (bu./acre)			
3.3—16— 4	-1.2	3.7	4.9	2.6
6.6—32— 8	-1.0	6.4	8.0	4.6
10—48—12	-1.5	9.0	9.3	5.6
13— 0— 0	1.9	5.6	0.9	2.4
13— 0—16	-0.1	2.7	0.4	0.8
0— 0—16	0.3	-1.7	-0.6	-0.6
0—16— 0	[2]	5.0	....[2]	....[2]
0—32— 0[3]	-0.7	2.1	6.1	2.8
0—64— 0[4]	-0.2	1.7	3.6	1.9

[1] The data for the 12 years were summarized under the three headings "No response years," "Nitrogen-phosphorus years," and "Phosphorus years."
[2] Data not complete for full 12 years.
[3] Applied biennially.
[4] Applied quadrennially.

Three groups of investigators studied the influence of phosphate fertilizer at the rate of approximately 20 pounds P_2O_5 per acre on the yield of winter wheat in southeastern Nebraska during 1938 to 1942 (*9, 27, 43*). Most of the experiments were conducted on soils of the Sharpsburg, Carrington and Pawnee series. The response of wheat to the phosphate fertilizer ranged from an increase in yield of 19.9 bushels to a decrease in yield of 7.5 bushels per acre. In 45 per cent of the 166 experiments the increases in yield due to phosphate fertilizer were 4 bushels or more per acre (Table 19). During the period 1938 to 1942 it was considered that an increase in yield of 4 bushels per acre was necessary for a profitable return from the use of the fertilizer.

TABLE 19.—Response of winter wheat to phosphate fertilizer in southeastern Nebraska during 1938 to 1942. Summary of 166 experiments.

Lbs. P_2O_5[1] applied	1938 20 expts.	1939 20 expts.	1940 90 expts.	1941 7 expts.	1942 29 expts.	Mean of 166 expts.
	Mean yield without fertilizer, bushels per acre					
0	17.5	16.0	24.4	11.2	29.4	22.9
	Mean increase due to phosphate fertilizer, bushels per acre					
20	3.5	4.7	2.8	8.9	5.7	3.9
	Experiments having increases in yield of 4 or more bushels per acre, %					
20	50	45	35	100	59	45

[1] Applications ranged from 18 to 23 pounds P_2O_5 per acre as superphosphate (43% P_2O_5). Neither nitrogen nor potassium fertilizers were included in these experiments.

It seems likely that a larger proportion of the experiments conducted in 1938 to 1942 would have shown increases in yield equal to or greater than 4 bushels per acre if the soils had been adequately supplied with nitrogen. For example, it has been noted since 1942 in southeastern Nebraska that phosphorus supplements without additional nitrogen are not likely to increase yields appreciably where the nitrogen level of the soil is low. The reverse is also true on soils very low in phosphorus. In some cases where both nitrogen and phosphorus were deficient and only phosphorus fertilizer was applied, vegetative growth was stimulated but smaller and shorter heads of grain were produced than where no treatment was applied (Figure 12). In fact, there is accumulating evidence to indicate that phosphorus fertilizer applied alone to soils more deficient in nitrogen than in phosphorus may cause a decrease in yield, perhaps as a result of accentuated nitrogen deficiency.

In seven experiments conducted in southeastern Nebraska during 1945, Fitts *et al.* (*10*) noted rather consistent increases in yield of winter wheat from phosphorus fertilizer, especially where nitrogen fertilizer was applied in the spring (Table 20). A mean increase of 2.9 bushels per acre was obtained where phosphate fertilizer alone was applied. Where 20 pounds of nitrogen was top-dressed in the spring, however, the increase in yield that could be attributed to the phosphate was 4.1 bushels per acre.

TABLE 20.—Summary of phosphorus fertilizer results on winter wheat in seven experiments conducted in southeastern Nebraska during 1945.

Treatment,[1] lbs. per acre of		Mean of 7 experiments
Nitrogen	P_2O_5	
		Average yield of check plots (bu./acre)
0	0	26.4
		Increase due to fertilizer (bu./acre)
0	30	2.9
20	30	9.8
20	0	5.7

[1] Phosphate placed with seed, nitrogen fertilizer broadcast in spring.

It is evident that the phosphate supplemented with nitrogen fertilizer in 1945 was more effective than phosphate used alone. The tests conducted in 1946 also indicated a need for supplemental nitrogen in obtaining optimum phosphorus response, as did those tests where phosphate had a beneficial effect on yield in 1948-1950 (Table 21). In 1947, however, nitrogen alone was more effective than nitrogen plus phosphorus fertilizer in raising yields on the Sharpsburg

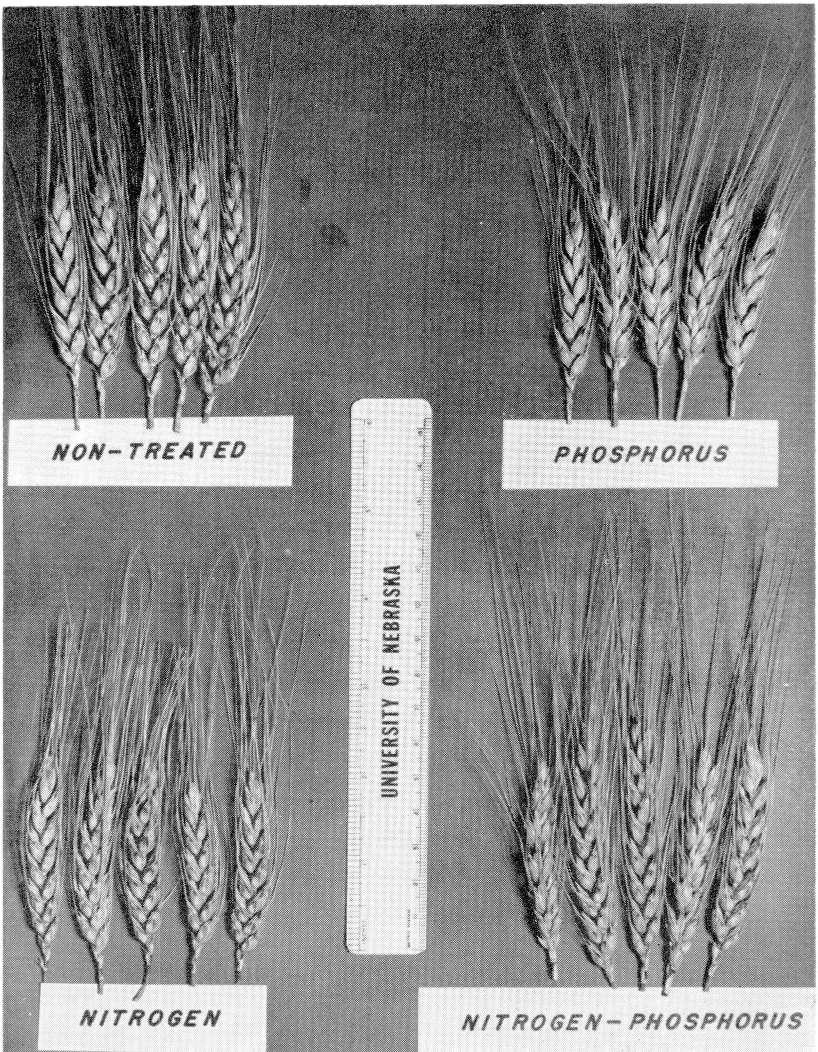


FIGURE 12.—Influence of fertilizer treatment on the size of wheat heads produced where the crop was grown on soil deficient in both nitrogen and phosphorus. Cass County experiment, 1949. A greater number of heads was produced in the phosphated and the nitrogen-treated plots than in the check plots. The heads, however, were smaller in size, especially on the phosphated plots. Only the plots receiving both nitrogen and phosphorus produced wheat heads to compare in size with those of the check plots.

TABLE 21.—The influence of nitrogen on phosphate fertilizer utilization by wheat in those experiments in Nebraska where phosphate had a beneficial effect on yield. 1946-1952.

Treatment, lbs. per acre N	P_2O_5	1946, 3 experiments	1948, 3 experiments[1]	1949, 4 experiments[2]	1950, 6 experiments[3]	1951, 7 experiments[4]	1952, 6 experiments[5]	Mean 29 experiments
		Mean yield without fertilizer, bushels per acre						
0	0	28.9	27.5	16.0	28.3	7.8	22.8	20.5
		Mean increases in yield due to fertilizer, bushels per acre						
0	30	*1.1*	*1.6*	*2.3*	*1.6*	*1.9*	*5.7*	*2.6*
40	30	9.2	16.5	7.4	15.5	6.8	9.0	10.4
40	0	4.6	10.6	2.3	8.2	1.7	0.2	4.0
		Mean increase due to phosphate where applied with nitrogen fertilizer, bushels per acre						
....	....	*4.6*	*5.9*	*5.1*	*7.3*	*5.1*	*8.8*	*6.4*

[1] Fields 1, 28 and 29 in Dodge, Adams and Kearney Counties.
[2] Fields 3, 13, 94 and 68 in Cass, Fillmore, Jefferson and Howard Counties.
[3] Fields 4, 5, 6, 33, 69, and 71 in Dodge, Nemaha, Richardson, Platte, Colfax and Johnson Counties.
[4] Fields 72, 74, 23, 8, 75, 70, 73 in Pawnee, Gage, Saline, Douglas, Nemaha, Colfax, Johnson Counties.
[5] Fields 47b, 70a, 77a, 73b, 8b in Harlan, Box Butte, Colfax (2), Pawnee and Dodge Counties.

soils investigated. It was reasoned that a very late spring freeze may have affected the phosphated plots adversely. The extent of damage due to the freeze was noted to be correlated with stage of maturity of the wheat, the most advanced grain being damaged most severely. Phosphate application had hastened maturity in most cases. Varietal effect on damage from the freeze appeared to bear out this reasoning in that the relatively early Pawnee variety suffered severely and the later maturing varieties, Nebred and Turkey, showed little or no damage. Had the freeze been a day or two later, it is quite possible that opposite results would have been obtained with respect to varieties and to phosphorus fertilization.

Weldon *et al.* (*9, 27, 43*) noted yield decreases from phosphate in several of the 1938 to 1942 tests, and attributed these to overstimulation. No doubt overstimulation was one cause, but it is now postulated that accentuated nitrogen deficiency from phosphate alone applied to soil not deficient in available phosphorus might well have been a contributing or even more important factor in many cases. Rather consistent yield reductions have been obtained from phosphorus fertilization of corn in Nebraska on soils not deficient in phosphorus but definitely lacking nitrogen. It has been observed in several wheat experiments in the past few years that yield reductions resulted from phosphorus fertilizers applied alone despite the fact that the phosphated plots showed no signs of excessive vegetative growth. In many cases they did not appear so thrifty as the check plots. Although the reduction in yield due to phosphorus treatment alone generally has not analyzed statistically significant, the trend has been too consistent to be overlooked.

In view of the above findings, it seems clear that phosphorus fertilization of wheat should be practiced only when the nitrogen requirement is taken care of as well. The latter can be done by previous cropping to forage legumes, manure application, or application of commercial nitrogen fertilizer. Furthermore, there appears to be no advantage in applying phosphorus fertilizer to soil, even in combination with nitrogen, if that soil is not deficient in phosphorus. The results actually may be detrimental.

Time and Rate of Applying Phosphorus Fertilizer

It is a well recognized fact that adequate available phosphorus must be present in the soil from germination to maturity of crop plants if optimum yields are to result. The supply of available phosphorus must be plentiful during the first stages of growth if the plants are to become firmly established in the soil with effective root systems and if adequate fall and spring stooling of the plants is to take place (see Figure 13). Duley (*8*), in studying methods of fertil-

FIGURE 13.—Field appearance of nontreated plot and plot receiving both nitrogen and phosphorus fertilizer (40 pounds N in spring and 30 pounds P_2O_5 per acre at planting time) at progressive stages of growth. Cass County experiment, 1949. Pictures taken on May 3 and 21, and June 20. In this experiment the following yield increases per acre were obtained: nitrogen alone, 2.5 bushels; phosphorus alone, 6.5 bushels; combination of nitrogen and phosphorus, 12.6 bushels.

izer application for wheat, stressed the desirability of phosphorus application with the seed at the time of planting. The necessity for this practice rather than broadcasting just before or after drilling has been recognized by the Nebraska Agricultural Experiment Station for many years. Average results from three experiments on phosphorus-deficient soils in southeastern Nebraska during 1952 bear out this principle in phosphate fertilizer use (also see Figure 14).

FIGURE 14.—Growth of wheat as influenced by method of phosphate application. Left, 30 pounds P_2O_5 drilled with seed; right, 30 pounds P_2O_5 broadcast before drilling. Yields were 33 and 18 bushels per acre respectively. 1952 experiment on calcareous sandy soil in Colfax County, Nebraska.

Treatment[1]	*Yield bu./acre*
No P_2O_5	18.1
30 lbs. P_2O_5 broadcast before final discing	24.1
30 lbs. P_2O_5 broadcast before drilling	20.2
30 lbs. P_2O_5 placed with seed	25.8
30 lbs. P_2O_5 broadcast after drilling	20.2

[1] Included uniform treatment of 40 pounds nitrogen per acre to all plots.

Recent studies for evaluating phosphorus needs in Nebraska soils have included the phosphate treatments drilled with the seed at the time of planting by means of a combination grain and fertilizer drill. Also, a granulated phosphorus carrier has usually been employed. Thus, fertilization is thought to have been the most efficient possible.

In fertilizer studies with winter wheat at the Agronomy Farm, Lincoln, during the period 1921-1933 (*30*), it was found that 16 pounds of available phosphorus per acre was inadequate and 48 pounds apparently was more than needed. The third rate employed, 32 pounds per acre, appeared to be near optimum. Twice the latter amount applied half as often was less effective and 16 pounds P_2O_5 per acre per year was more effective than 32 pounds per acre applied biennially (Table 18).

Experiments on six phosphorus-deficient soils in southeastern Nebraska in 1950 and 1952 using a superphosphate carrier showed the following averages for different rates of phosphate:

Rate	*Yield increase bu./acre*
20 lbs. available phosphorus (P_2O_5)/acre	9.1
30 lbs. available phosphorus (P_2O_5)/acre	11.1
50 lbs. available phosphorus (P_2O_5)/acre	11.7

Four of the sites were on soils of extremely low available phosphorus content by Nebraska standards. From these and other unpublished data, therefore, it has been concluded that 20 to 30 pounds of available phosphorus per acre, *when applied with the seed,* is adequate for winter wheat grown on average phosphorus-deficient soils of the state.

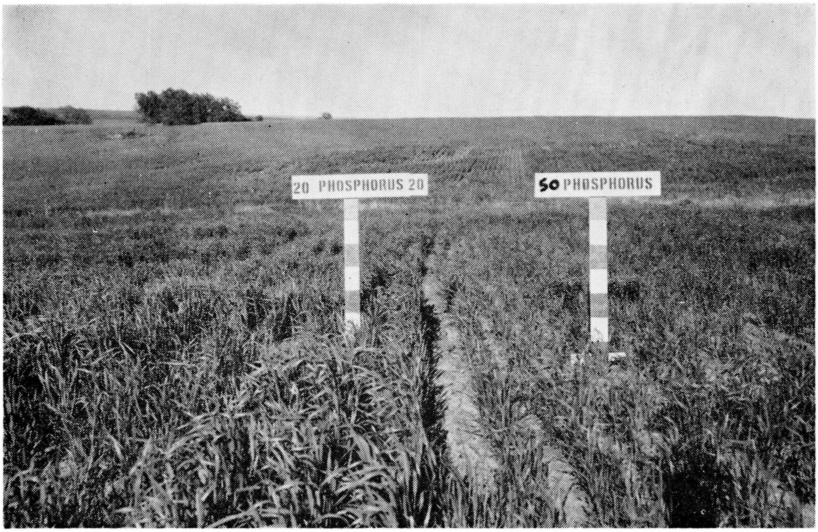
In the case of annual crops such as wheat, it is a more efficient fertilizer practice to supply the approximate amount of nutrient supplement needed by the current crop annually than to add a large amount one year for two or more years' crop growth. This is evidenced by the residual effects of phosphate applied to the 1950 crop on yields of wheat obtained in 1951 (see Figure 15).

Time and rate	1951 wheat yield increase *bu./acre*	Total response, 1950 and 1951 *bu./acre*	Bu. wheat returned per lb. P_2O_5 applied
20 lbs. P_2O_5/acre 1950[1]	2.7	14.0	0.70
30 lbs. P_2O_5/acre 1950[1]	2.6	17.1	0.57
50 lbs. P_2O_5/acre 1950[1]	1.4	16.9	0.34
20 lbs. P_2O_5/acre 1950[1] and 1951	9.9	21.2	0.53

[1] Fertilizer applied in the previous fall at planting time for the 1950 crop, similarly for 1951 crop. Mean of three experiments.

Effectiveness of Different Phosphate Carriers

Little early work was done in Nebraska comparing the relative effectiveness of different types of phosphorus fertilizer materials. In most experiments conducted in the past ordinary or concentrated superphosphates were employed as the carriers. In the few comparisons which were made between rock phosphate and superphosphate, the former proved ineffective for crops grown on Nebraska soils. This



May 1951

Left—20 pounds P_2O_5 per acre applied in 1950 and 1951. **Right—50 pounds P_2O_5 per acre applied in 1950.**

FIGURE 15.—Twenty pounds available phosphorus applied annually to winter wheat is more effective for increasing yields than 50 pounds applied biennially.

is in agreement with results at other midwestern and western experiment stations.

In the 1938-1942 phosphorus studies with wheat in southeastern Nebraska, two experiments included calcium metaphosphate as well as the standard superphosphate treatment. The metaphosphate proved slightly more effective than superphosphate. The 1950 fertilization work with wheat included three phosphorus carrier experiments on phosphorus-deficient acid and calcareous soils. The sites employed for studying phosphorus carriers were carefully selected to represent various conditions of phosphorus deficiency in Nebraska: first, strongly acid soil on glacial drift (Johnson Co.); second, calcareous sandy soil (Colfax Co.); and third, moderately acid soil on loess (Nemaha Co.). The first two sites embodied soils of extremely low available phosphorus content by Nebraska standards. The carriers used were ordinary and concentrated superphosphate, calcium metaphosphate, nitric phosphate (17-22-0), fused phosphate,[4] and rock phosphate, and seed treatment was effected with sodium monobasic orthophosphate. In comparing these carriers (except seed treatment), the rather light rate of 20 pounds P_2O_5 per acre placed with the seed was used in order to better measure relative efficiency of the different carriers

[4] The nitric phosphate and fused phosphate were pilot plant products of TVA.

for supplying phosphorus to the wheat. Comparable experiments, with slight modification, were again conducted on similar soils in 1952. Table 22 summarizes the responses noted in these six experiments.

Rock phosphate at the heavy rate of 700 pounds per acre caused less than half the yield response obtained with superphosphate on acid soils, and had no effect on yield on calcareous soil (Figure 18). Calcium metaphosphate was apparently about as effective as the superphosphates on acid soils but was much less effective on the calcareous soils investigated. The nitric phosphate (17-22-0) employed in 1950 was less effective than superphosphate, however, a 12-32-0 nitric phosphate was superior to superphosphate in 1952 on acid soils. Neither of the nitric phosphates appeared promising on calcareous soil. Results from the fused rock phosphate and the seed absorption of phosphate treatments were not promising on either the acid or calcareous soils (Figures 16 and 17). A greater residual effect was noted with the succeeding crop from such carriers as rock phosphate and fused phosphate than from superphosphate. However, this carryover was not sufficient to make them comparable to superphosphates for use on phosphorus-deficient Nebraska soils.

Of other phosphatic materials on the fertilizer market, various studies have indicated that ammoniated phosphates have approximately equal availability with the superphosphates from which they have been derived. Data from three 1952 experiments on phosphorus-deficient soils substantiate this contention. The mean yield with three ammoniated phosphates on the Nebraska fertilizer market was 24.4 bushels per acre compared with 24.5 bushels from a comparable mixture of ammonium nitrate and concentrated superphosphate.

There have been some indications that with certain soil conditions ammonium phosphates give more efficient utilization per unit of phosphate applied than monocalcium phosphates. This point was investigated with wheat in southeastern Nebraska during 1951 and 1952. As an average of nine experiments, identical yields were obtained with ammonium phosphate and the comparable ammonium nitrate and superphosphate mixture. Where used on a calcareous soil in one of the 1952 experiments, however, the ammonium phosphate was definitely superior to the mixture.

It is doubtful that seed treatment with nutrient solutions will have wide practical application. Results with phosphate absorption were not promising in the 1950 and 1952 experiments cited, in part because of the deleterious effect on germination and consequent stand reduction, and in part due to the fact that adequate phosphate could not be provided by the procedure (see Figure 16). The same prin-

TABLE 22.—Comparison of different phosphate carriers applied at the rate of 20 pounds P_2O_5 per acre for winter wheat in Nebraska. 1950 and 1952.

Nature of soil	Years	Number of experiments	Yield increase, bu./acre due to:[1]						
			Superphosphate	Ca meta-phosphate	Fused phosphate	Seed treatment[2]	Nitric phosphate		Rock phosphate[3]
							17-22-0	12-32-0	
Acid soils	1950 & 1952	4	3.3	3.2	1.9	–1.8	....	....	....
	1950	2	5.6	....	....	....	2.1	....	2.4
	1952	2	1.0	....	....	....	....	4.0	....
Calcareous soils	1950 & 1952	2	13.1	3.7	–2.5	–4.5	....	....	....
	1950	1	9.2	....	....	....	4.5	....	–1.5
	1952	1	17.0	....	....	....	....	5.0	....

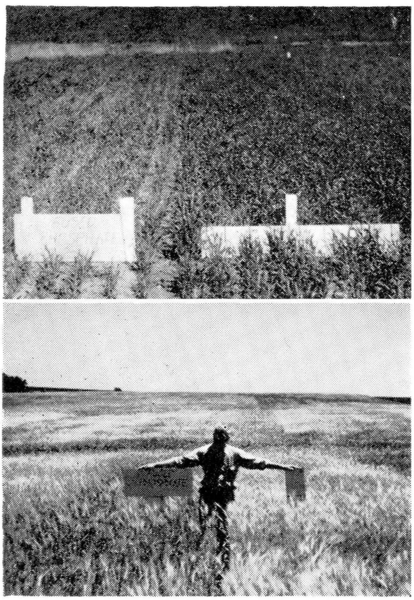
[1] Yield increase indicated is the difference in yield between the nitrogen fertilizer treatment alone and the combined nitrogen and phosphate treatment. All phosphate applied with seed at planting time. A total of 40 pounds of nitrogen per acre supplied to all plots.

[2] In 1950, a 5 per cent solution of sodium monobasic orthophosphate used, supplying approximately 0.6 pound P_2O_5 per acre. In 1952 a 5-10-5 "liquid fertilizer" employed at the rate of 1 pint per bushel of seed which supplied approximately 0.15 pound P_2O_5 per acre.

[3] Rock phosphate applied at the rate of 700 pounds per acre, supplying approximately 20 pounds available P_2O_5 and 225 pounds total P_2O_5 per acre.

FIGURE 16.—Marked fertilizer response (left) of wheat to 20 pounds P_2O_5 drilled with seed as compared with no response (right) to seed treatment with a fertilizer solution. Yields were 28 and 12 bushels per acre respectively. 1952 experiment on calcareous soil in Nebraska.

Residual effect, 1951
Left—fused phosphate.
Right—superphosphate.



May 11 and June 28, 1950
Left—fused phosphate.
Right—superphosphate.

FIGURE 17.—Field appearance of plots treated with 20 pounds available phosphorus per acre as fused phosphate and superphosphate. Strongly acid soil in Johnson County.

June 28, 1950
Left—superphosphate. Right—rock phosphate.

FIGURE 18.—Field appearance of plots treated with 20 pounds P_2O_5 per acre as superphosphate (47 pounds) and rock phosphate (700 pounds). Strongly acid soil in Johnson County.

ciples are expected to apply with nitrogen solutions marketed for seed treatment, or with combined nitrogen-phosphorus nutrient solutions. Practicality of the procedure then is limited by (1) the extremely small amounts of materials applied on an acre basis and resultant extremely small potential effect on yields, and (2) the higher cost per unit of nutrients than in liquid and dry fertilizer materials meant for soil application.

Effect of Phosphorus on Quality of Winter Wheat

Some investigators in other states have indicated that phosphorus fertilizers may enhance the quality of wheat by increasing the test weight. In the work of Weldon *et al.* (*9, 27, 43*) on phosphorus fertilization of wheat in southeastern Nebraska from 1938 to 1940, the test weights of wheat produced on the treated and nontreated plots were compared. These studies indicated, as an average of 130 tests, that phosphorus fertilizer applied alone is not likely to have any appreciable effect on test weight of the grain, except possibly in cases of extreme phosphorus deficiency. Further observations of test weight in relation to fertilizer treatments in recent years suggest that phosphorus fertilizer applied alone will have little if any effect on test weight. Applied with nitrogen to soil deficient in both nitrogen and

TABLE 23.—Influence of fertilizer treatments on the test weight of wheat in Nebraska. 1948-1952.

Treatment Lbs./acre of $N-P_2O_5-K_2O$	1948	1949	1950	1951	1952	Mean for five years, 1948-1952
	lbs./bu.	*lbs./bu.*	*lbs./bu.*	*lbs./bu.*	*lbs./bu.*	*lbs./bu.*
Southeastern Nebraska						
0—0—0	60.1 (1)[1]	56.4 (1)	58.8 (4)	54.7 (3)	60.2 (3)	58.0
40(S)—0—0	60.7	55.1	58.5	52.5	59.9	57.3
40(S)—30—0	60.7	57.9	58.4	55.8	60.1	58.6
40(S)—30—30	60.9	57.6	59.1	56.5	60.0	58.8
East-south-central Nebraska						
0—0—0	59.2 (6)	57.0 (9)	58.0 (4)	57.5 (4)	58.5 (6)	58.0
40(S)—0—0	59.5	56.5	58.3	57.6	58.1	58.0
40(S)—30—0	59.6	57.3	59.8	57.9	58.7	58.5
40(S)—30—30	59.7	57.1	58.9	58.0	58.9	58.5
West-south-central Nebraska						
0—0—0	59.4 (4)	56.5 (1)	58.6 (3)	57.7 (8)	60.2 (3)	58.7[2]
40(S)—0—0	59.5	56.6	56.4	58.0	57.8	57.6
40(S)—30—0	59.4	56.9	57.4	......	57.4	57.8
40(S)—30—30	59.7	55.7	57.1	......	57.1	57.4
Western Nebraska						
0—0—0	59.6 (5)	58.3 (4)	58.8 (3)	57.8 (3)	55.1 (7)	57.9
40(S)—0—0	59.1	56.2	57.7	56.7	52.7	56.5
40(S)—30—0	59.2	57.0	57.8	57.5	52.2	56.7
40(S)—30—30	59.1	56.7	57.9	57.7	51.8	56.6

[1] Figures in parentheses represent number of experiments.
[2] Average figures for west-south-central Nebraska do not include 1951 data.

phosphorus, it may elevate test weight slightly. Phosphorus fertilizer has a slight but not complete moderating effect on the apparent depressing action of nitrogen fertilizer on test weight (Table 23).

Phosphorus fertilization of wheat also has been linked with the protein content of grain produced in some parts of the country. Results obtained to date in Nebraska, however, generally have shown a negative relationship between phosphorus fertilizer supplements and the protein in the grain, i.e., protein percentage has dropped with phosphorus fertilizer increments. This has obtained even on those soil areas where phosphorus fertilization has increased yields. Table 24 of 1948-1952 results shows an indication of a drop in protein percentage from phosphorus application alone and a smaller protein percentage increase from combined nitrogen-phosphorus fertilization than from nitrogen fertilizer alone. Of the 72 tests for which protein data are available, only 31 per cent showed an increase in protein due to phosphorus fertilizer alone and 37 per cent showed an increase for a combination of nitrogen and phosphorus fertilizer compared with nitrogen fertilizer alone. This compares with 82 per cent of the

TABLE 24.—Effect of phosphorus fertilizer on the protein content of winter wheat. Nebraska, 1948-1952.

Treatment Lbs. per acre of N	P_2O_5	1948 Average of 17 expts.	1949 Average of 14 expts.	1950 Average of 13 expts.	1951 Average of 3 expts.	1952 Average of 15 expts.	Mean for five years 1948-1952
		Check plot protein content (per cent)					
0	0	12.4	11.3	11.7	12.0	12.2	11.9
		Increased protein due to fertilizer (per cent)					
0	30	–0.1	–0.2	–0.3	–0.7	–0.1	–0.3
40	30	2.3	0.4	1.3	–0.4	1.5	1.0
40	0	2.5	0.6	1.1	0.8	1.7	1.3
		Increased protein due to phosphorus where applied with nitrogen (per cent)					
		–0.2	–0.2	0.2	–1.2	–0.2	–0.3

experiments showing significant protein increases from nitrogen fertilizer only. No doubt this further verifies a reduced nitrogen utilization by plants growing on nitrogen-deficient soil where the available phosphorus supply is raised to a relatively high level. It seems apparent, therefore, that fertilization of wheat with phosphate is not likely to increase the protein content of the grain unless phosphorus deficiency seriously curtails crop growth.

The old practice of phosphating the legumes on phosphorus-deficient soil is still considered a good one, as it stimulates the legumes to heavier forage production and greater nitrogen fixation. Of all crops grown in Nebraska, the legumes respond best to phosphorus fertilizer, so use of phosphate on these crops is likely to provide most profitable returns. This is considered sound soil management procedure for southeastern Nebraska and irrigated sections of the state where phosphorus is deficient and moisture adequate for legume production.

Relation of Soil Properties to Phosphorus Fertilizer Response

For the zonal soils under investigation, consistent response to phosphorus fertilization was obtained only on the Sharpsburg and Carrington series (Table 25). The Crete, Hastings, Holdrege, Keith and Sherman soils as a general rule are adequately supplied with available phosphorus for good wheat production. It should be mentioned, however, that many of the soils developed from glacial material in southeastern Nebraska of lesser importance for wheat production such as the Pawnee, Burchard and Steinauer series, severely eroded areas and many sandy soils are known to be deficient in phosphorus.

Phosphorus deficiency is often recognized in conjunction with three definite soil conditions, viz., extreme sandiness, strong acidity and high lime content. The first two go somewhat hand-in-hand, since very sandy soils are often quite acid in reaction. In the case of strongly acid soil reaction, the solubility of iron and aluminum compounds in the soil is increased and according to Heck (*15*), the hydrates of these elements combine with available phosphorus, residual and applied, to form complex insoluble and unavailable phosphate compounds. On the other hand, McGeorge (*24*) contends that available phosphate is converted to insoluble and unavailable hydroxy or carbonate apatite compounds in soils containing excessive quantities of calcium carbonate.

In addition to the indirect effects soil reaction has on the availability of phosphorus compounds in the soil, it is known that strong alkalinity has a direct depressing effect on the absorption of phosphorus by plants. A pH of approximately 8.0 has been recognized as the upper limit for ready phosphorus absorption by plants. This factor does not warrant consideration, however, with most zonal soils in Nebraska devoted to wheat production, for soil reaction is generally in the medium acid to neutral range (Table 1). It is a factor for consideration with alkaline terrace and bottomland soils and eroded calcareous upland soils where wheat is grown.

The effectiveness of applied phosphorus has been increased in recent years by two practices in the manufacture and spreading of phosphate fertilizers, practices which reduce fixation. First, the fertilizer is being granulated by many manufacturers, thus reducing the surface area of the fertilizer materials exposed to reversion reactions in the soil. Secondly, machinery has been devised for placing the phosphate fertilizer in concentrated bands in the root zone, further limiting reversion reactions.

Only four of the recent experiments with fertilization of wheat have been carried out on sandy and/or calcareous soils. Results from these experiments (see Wann soils, Table 25) along with many recent tests with spring small grains, rye and even grasses have indicated a general need for phosphorus supplements in obtaining maximum yields under these soil conditions.

It has been implied that need for supplemental phosphorus usually can be predicted for wheat growing on extremely sandy or highly calcareous soils. Prediction of phosphorus need on other soils, including most of the zonal soils of the state, is much more difficult. In the latter case, the consideration of several factors is necessary. Some of the more important of these factors are past fertilization practice, past cropping history as to time and amount of crop removal, nature of the soil clay, soil reaction, and organic matter content. It is reasonable that a soil which has received regular and frequent supplements

TABLE 25.—Effect of phosphorus fertilizer on the yield of winter wheat grown on the major wheat producing soils of Nebraska. 1945-1950.

Year	Number of experiments	Yield of check plots, bu./acre	Increase in yield due to 30 lbs. of P_2O_5,[1] bu./acre
		SHARPSBURG	
1945	3	27.6	5.6
1946	3	28.9	4.6
1948	1	22.9	7.1
1949	1	20.3	10.1
1950	5	32.2	4.9
1951	1	14.8	1.9
1952	1	38.0	8.0
Mean			6.0
		CARRINGTON	
1945	1	27.5	3.7
1950	1	17.4	8.1
1951	2	5.5	10.0
1952	1	14.3	2.4
Mean			6.1
		CRETE	
1947	2	14.4	–1.8
1948	3	33.2	–0.7
1949	5	14.1	0.1
1950	2	17.5	–1.4
1951	2	15.3	2.4
1952	2	20.0	0.0
Mean			–0.2
		HASTINGS	
1948	4	25.6	1.8
1949	4	15.0	0.6
1950	1	35.7	4.7
1951	2	10.5	0.5
1952	2	29.0	0.0
Mean			1.5
		HOLDREGE	
1947	1	23.3	1.4
1948	2	49.6	2.1
1950	3	31.8	–0.1
1951	2	22.6	–1.4
1952	3	22.7	–0.7
Mean			0.3
		KEITH, SHERMAN and ROSEBUD	
1947	1	21.7	0.2
1948	7	43.6	–0.3
1949	6	18.6	0.0
1950	3	12.2	1.3
1951	2	30.2	0.2
1952	7	19.7	0.7
Mean			0.4

[1] Yield increase due to phosphorus determined as the difference between the yields from a combined nitrogen and phosphorus treatment and those where only nitrogen was applied.

TABLE 25.—*Continued.*

Year	Number of experiments	Yield of check plots bu./acre	Increase in yield due to 30 lbs. of P_2O_5,[1] bu./acre
		WANN[2]	
1949	1	10.2	5.2
1950	1	18.5	13.0
1951	1	3.4	7.2
1952	1	11.0	21.0

[2] A sandy calcareous first bottomland soil. Not a major wheat-producing soil, but included to study the influence of phosphatic fertilizers with a soil condition where phosphorus deficiency was known to exist.

of phosphorus in manure and commercial phosphate fertilizer is not likely to be so deficient as a like soil without this fertilization history. It is also logical that of two soil areas identical in nature, the one which has been cropped longest with greatest crop removal, other factors being equal, is likely to be most deficient in phosphorus. Thus, these historical items are of utmost importance in predetermining need for supplemental phosphorus.

Soil reaction, as indicated by pH values, is certainly one of the most important factors governing availability of soil phosphorus. In the case of a high pH of 7.7 or more with zonal soils, the presence of excess lime is indicated. At the other extreme, pH values of less than 5.5 indicate increasing solubility of iron and aluminum compounds in the soil and consequent precipitation of residual and applied phosphate. It is true that pH determined over a limited range is perhaps of little specific value in predicting phosphorus requirements of soils. This was observed by Miller (*26*) in studying phosphorus fertilization results with wheat in southeastern Nebraska on soils having a pH range in the surface horizon of approximately 5.5 to 6.0. Experimental results have shown, however, that the most acid soils in Nebraska as a group, i.e., those in southeastern Nebraska such as the Sharpsburg, and the alkaline calcareous soils in this and other sections, are most likely of all Nebraska soils to be deficient in phosphorus. Thus the pH value of a given soil is considered one of the most reliable aids in predetermining whether or not phosphorus supplement is needed. Figure 19 bears out this belief for the entire pH range of soils which has been studied. It would appear from this graph that the approximate optimum pH range for wheat production in relation to phosphorus availability is 6.2-7.0.

That organic matter content may serve as an index of possible need for supplemental phosphorus is borne out by results in two 1948 experiments on Hastings soils in south-central Nebraska. Norm-

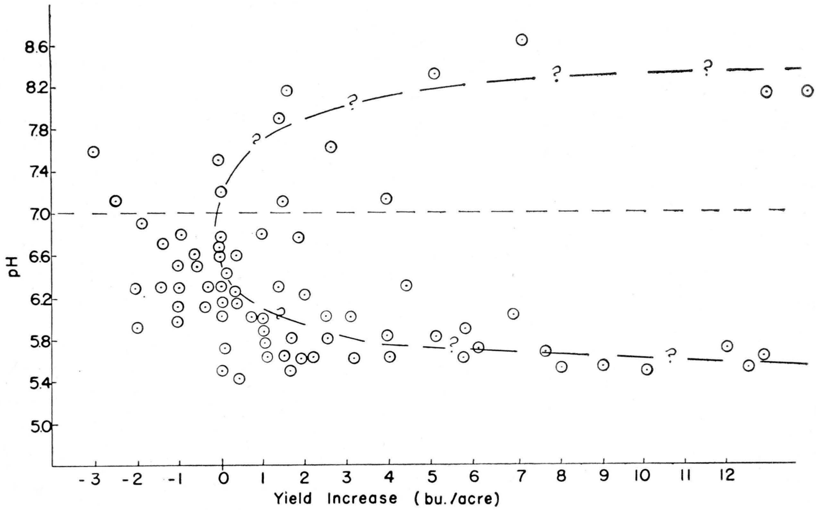


FIGURE 19.—Relation between pH of surface soil horizon and yield increases resulting from phosphorus fertilization. Nebraska, 1948-1952.

ally phosphorus fertilization has not increased yields of wheat and other crops on these soils. At these two sites, however, where erosion has been quite severe and the soils are now relatively low in organic matter content, an average increase in yield of 5.3 bushels per acre due to phosphate was obtained. The organic matter values of 1.95 and 1.38 per cent are considerably lower than those found with Hastings soils which have not been eroded appreciably. No satisfactory laboratory quick test has been devised for measuring the total quantity of organic soil phosphorus, nor the rate at which it is likely to be released in inorganic form for crop use. For this reason, most quick tests for soil phosphorus disregard this important source of phosphorus. Therefore, knowledge of the soil's organic matter content is of considerable importance in predicting the need of crops for supplemental phosphorus.

Laboratory quick tests serve as a further aid for predetermining the probability of need for phosphorus fertilizer. Testing procedures have been devised by many investigators for extracting soil phosphorus and some have proved quite dependable in given areas. Research continues for improved testing procedures. The chief requirement of any procedure is that the test be correlated with field conditions and results from fertilizer trials in a specific region. Certainly the primary limitation of soil testing as practiced by many is neither in the reagents employed nor the testing results but in the lack of correlation between the soil tests and field response from fertilizer applications.

Soluble phosphorus in these studies was determined on the 0- to 8-inch soil samples from 1948-1952 test plot sites to achieve further correlation between laboratory testing results and field results from phosphorus fertilizer application. For this reason, reagents and procedures identical to those employed by the Soil Testing Laboratory were used. In this laboratory procedure phosphorus is determined on a 1½:1 extraction, thus the amount of phosphorus in the extraction can be expected to be very small. This accounts for the very low figures of 0.03 to 0.65 p.p.m. of phosphorus portrayed in Figure 20 where soluble soil phosphorus is plotted against yield increase from phosphorus fertilization of continuously cropped fields. Since phosphorus fertilizer applied alone had little effect on yields at most locations, the yield increase due to phosphorus as plotted has been obtained by taking the yield difference between the nitrogen-phosphorus-fertilized plots and the nitrogen-fertilized plots. A perfect relationship could not be expected because of the many variables which could cause deviation. Nevertheless, a highly significant correlation is apparent (Table 26 and Figure 20). The regression line indicates

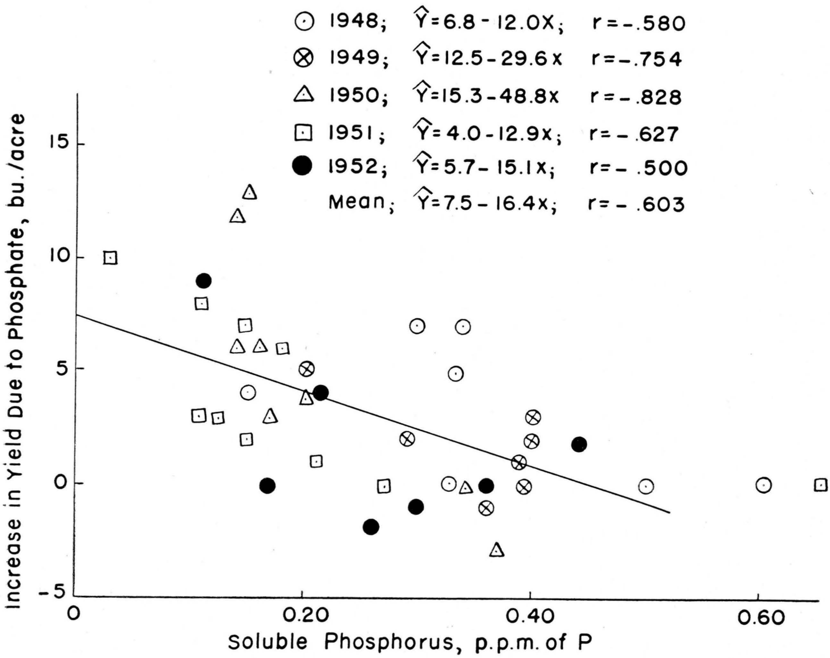


FIGURE 20.—Relation between soluble phosphorus content of soil (1½:1 extraction) and yield increase from phosphorus fertilizer application, 1948-1952.

TABLE 26.—Correlation of soluble phosphorus with yield of winter wheat and with the increase in yield of winter wheat due to phosphate fertilizer. Nebraska, 1948-1952.

Correlation	Correlation coefficient (r)
Wheat after small grain (40 fields)	
Yield with soluble phosphorus	.216
Yield as percentage of maximum yield with soluble phosphorus	.348*
Increase in yield due to phosphate with soluble phosphorus	.603**
Increase in yield due to phosphate as percentage of maximum yield with soluble phosphorus	.618**
Wheat after fallow (25 fields)	
Yield with soluble phosphorus	−.071
Yield as percentage of maximum yield with soluble phosphorus	−.200
Increase in yield due to phosphate with soluble phosphorus	−.296
Increase in yield due to phosphate as percentage of maximum yield with soluble phosphorus	−.216

* Significant at the 5% level, significant.
** Significant at the 1% level, highly significant.

that for the period 1948-1952 a response to phosphorus fertilization could be expected if the testing procedure showed less than approximately 0.45 p.p.m. soluble phosphorus and a profitable response at less than approximately 0.30 p.p.m. soluble phosphorus. On the basis of the first year's correlation of this testing procedure in 1948, predictions of phosphorus response for the 1949 and 1950 experimental locations were almost 100 per cent correct. It may be stated in favor of the testing procedure that on the basis of knowledge of the area and general past fertilizer results, probably no one would have predicted a yield increase from phosphorus in fields 28 and 29 during 1948, field 13 during 1949, fields 4, 33, 39 and 62 during 1950, and field 23 during 1951. In other words, soil series designation from apparent soil properties and location are not adequate criteria for predicting supplemental phosphorus needs.

This apparent correlation with the testing procedure is not in agreement with the observations of Miller (*26*). He used substantially the same extracting reagent, but employed a percolation procedure. He stated that the test was of no "material value as an aid in the prediction of profitable (phosphorus) response. Apparently factors other than phosphate availability are involved in this problem." In view of the nitrogen-phosphorus relationship which has been outlined here, it is proposed that nitrogen was the major missing factor. It is now believed that the test can be of material value in predicting phosphorus requirement where it is supplemented by cropping and fertilization history, and information pertaining to soil reaction, texture, and organic matter content and where the crop's nitrogen requirement is satisfied.

The lack of correlation between the testing procedure and yield response to phosphate on fallowed fields can probably be attributed to the general lack of phosphate response in the summer fallow area of Keith, Sherman and Rosebud soils.

POTASSIUM FERTILIZER FOR WINTER WHEAT

The available potassium content of soils developed in regions of low rainfall is normally high, and potassium fertilization has generally given little if any response. This has been the observation in Nebraska to date. Further, the laboratory measurements made in this study indicate very high exchangeable potassium of the zonal soils under investigation (Table 1).

Little or no benefit accrued from potassium fertilizers applied for winter wheat grown on Sharpsburg soil at Lincoln during the 12-year period 1921-1932. In fact, an addition of 16 pounds K_2O with 13 pounds of nitrogen per acre resulted in an average depression of 1.6 bushels per acre below the yield with nitrogen fertilizer only (see Table 18, p. 44).

In the seven tests conducted by Fitts *et al.* (*10*) in southeastern Nebraska during 1945, the combined nitrogen-phosphorus-potash treatment included in the experiments averaged no better than the combined nitrogen-phosphorus treatment, and in no case was a significant yield difference obtained in favor of the potash. Similar results were noted in 1946, 1947, 1949, 1950, 1951 and 1952 (Table 4), except that a yield depression from the potassium fertilizer was often apparent. In several of these tests the yield depression was significant at the 5 per cent level.

An apparent yield increase from potassium fertilizer was noted in the 1948 experiments. This was the result of two tests which showed barely significant yield increases from the potash (Table 4). Increase in yield due to potassium would not be expected on the basis of the soil properties at the two locations (fields 12 and 27, Crete and Hastings soils, respectively). The soils at the two sites were relatively noneroded, medium- to fine-textured, relatively high in organic matter and medium acid in reaction. There was no factor of excessive calcium or other condition known to be inhibitive to potassium absorption. Exchangeable potassium was 1.5 m.e./100 g. in the surface horizon at both locations. In view of the other soil conditions noted, all favorable to potassium absorption, there was no apparent reason why this large amount of exchangeable potassium should not have supplied the crop with adequate quantities of the element. This does not mean that potassium deficiency is impossible with these Hastings and Crete soils, but it does seem improbable at present. Certainly experiments with wheat as well as other crops more responsive to potash fertilizers should be continued in this area for further evaluation. It is possible that some unrecognized condition of these soils has an adverse effect on potassium absorption by crops, thus reducing the significance of high exchangeable potassium.

In comparing the protein content of winter wheat produced with different fertilizer treatments in the 1948-1952 experiments, it is evident that potash had little or no effect on protein (Table 27).

In view of field observations and research findings to date, there is no basis now for widespread use of potassium fertilizer for wheat grown on the major soils devoted to wheat production in Nebraska. It is known that certain small areas of very sandy soils are deficient in this element, but little of this soil is used for wheat production.

TABLE 27.—Effect of potassium fertilizer on the protein content of winter wheat. Nebraska, 1948-1952.

Treatment, $N-P_2O_5-K_2O$, lbs./acre	1948 Average of 17 expts.	1949 Average of 14 expts.	1950 Average of 12 expts.	1951 Average of 11 expts.	1952 Average of 15 expts.	Mean for five years, 1948-1952
	Average protein content of check plots (per cent)					
0—0—0	12.4	11.3	11.8	11.5	12.2	11.8
	Average increase in protein due to fertilizer (per cent)					
40—0—0	2.5	0.6	1.1	0.5	1.7	1.3
40—30—0	2.3	0.4	1.1	0.0	1.5	1.1
40—30—30	*2.2*	*0.6*	*1.0*	*0.2*	*1.6*	*1.1*

MIXED FERTILIZERS FOR WINTER WHEAT

The need for nitrogen, phosphorus and potassium fertilizers by winter wheat grown on major Nebraska soils has been summarized in the preceding sections. It is apparent that any Nebraska soil deficient in phosphorus is also likely to be deficient in nitrogen. Where both deficiencies exist, there is a place for a mixed nitrogen-phosphorus fertilizer. In general a 1-4-0 or 1-5-0 ratio fertilizer is thought to have greatest application for this purpose, supplying the phosphorus requirement and a small amount of nitrogen for starter at planting time. Thus, 100 pounds per acre of an 8-32-0 grade applied with the seed at planting would supply all of the phosphorus needed. This basic treatment followed by approximately 30 pounds of nitrogen in the spring in the form of some effective straight nitrogen carrier would satisfy the fertility supplement needs of wheat grown on average Nebraska soils deficient in both elements.

For average zonal soils similar to those studied here there is but slight advantage in using the mixed materials (1-3-0 ratio employed here) over individual fall and spring applications of phosphate and nitrogenous fertilizers respectively (see Table 9). For soils of very low nitrogen fertility, however, the small amount of nitrogen supplied in the mixed fertilizer is almost certain to induce a better stand, more stooling and more rapid early spring growth of the wheat. This could have a marked effect on yield.

A 1-1-0 ratio fertilizer such as a 15-15-0 grade, or a 3-2-0 ratio, would seem ideal for wheat grown on soil known to be deficient in both nitrogen and phosphorus. With such materials only one fertilizer operation is required. The hypothesis is correct so long as the fertilizer is not placed with the seed, a practice known to be most effective in the fertilization of wheat with phosphate. Placement of the needed amount of nitrogen with the seed will cause serious stand reduction due to inhibited germination if the seedbed is dry at and immediately following planting. With adequate moisture at and following planting, this restriction does not apply. Neither does it apply if the fertilizer is broadcast prior to plowing or discing.

To date it is unnecessary to employ mixed fertilizer containing nutrient elements other than nitrogen and phosphorus for wheat grown on major wheat-producing soils of the state. Calcium is known to be deficient in some of the more acid soils, but its deficiency has little other than an indirect effect on wheat, being most needed by leguminous crops.

SUMMARY

The results of recorded fertilizer studies with winter wheat in Nebraska are presented for the period 1916 through 1952. In conjunction with the field experiments, laboratory investigations were made on soil samples collected at the sites of the 1948-1952 experimental plots, and some of the physical and chemical properties of the major zonal soils devoted to wheat production were studied in relation to the supplemental nutrient requirements of the crop.

The major zonal soils upon which wheat is produced in Nebraska are recognized as the Sharpsburg, Crete, Hastings, Holdrege, Keith, Sherman and Rosebud soil series. Laboratory investigations of samples from these series show a gradual decline in moisture equivalent, organic matter and cation exchange capacity, and a progressive increase in pH, soluble phosphorus, percentage base saturation, percentage calcium saturation and percentage potassium saturation from east to west across the state. Percentage exchangeable magnesium saturation is noted to be similar for all soils, and percentage sodium saturation is low with all series. Nitrification rate is noted to be quite low for all series. This accounts for the excellent results which have been obtained from nitrogen fertilization of winter wheat throughout much of the continuously cropped area of the state as

well as some of the dry farming region where summer fallowing is practiced.

Comparison of current organic matter values for the different series with earlier determinations made on the same soils in virgin sod shows a marked reduction in this soil component. The reductions range from approximately 30 per cent in southeastern and western Nebraska to slightly over 40 per cent in south-central Nebraska. This gives some explanation for the widely observed nitrogen deficiency of crops throughout the state at the present time.

It is demonstrated that winter wheat absorbs much of the nitrogen required for high yields between the period when growth commences in the spring and the heading stage. Most efficient use of supplemental nitrogen applied to the crop will usually result when the application is made early during this period rather than at planting time or late in the period. This is thought to be of extreme importance to Nebraska farmers in that it permits an evaluation of stand and moisture supply well into the second year of the crop's growth. If both factors are satisfactory and nitrogen deficiency is known to exist, fertilizer application should be a good risk. This assumes, of course, a sufficient soil nitrogen supply in the fall for a good stand and adequate stooling of the crop. In the case of extreme nitrogen deficiency, a split application of the nitrogen at planting time and in the spring probably must be made to obtain most efficient moisture utilization and response to the fertilizer by the crop.

Consistent yield responses are reported for nitrogen applications in the spring (3 to 6-inch growth stage) at rates of 40 pounds of nitrogen per acre in most sections except the panhandle of western Nebraska. The yield increases have ranged from 5 to 14 bushels per acre for the zonal soils studied in the eastern two thirds of the state, averaging about 8 bushels per acre. Generally, spring applications have been slightly superior to fall applications from the combined standpoints of grain yield and protein content of the grain.

In deriving optimum returns from the nitrogen fertilizer, phosphate usually must be included on the Sharpsburg and Carrington soils of southeastern Nebraska. This is not generally true with the other major soil series investigated.

Nitrogen carrier studies with wheat show that materials carrying part or all of their nitrogen in nitrate form are generally superior to those containing only the ammonium form of nitrogen for spring broadcast treatments. Both of the former are superior to calcium cyanamide. The urea form of nitrogen appears to be about equally as effective as the nitrate form. Anhydrous ammonia applied at an approximate 6-inch depth in the fall has given equivalent results to fall and spring broadcast ammonium nitrate. Early spring application of anhydrous ammonia in many years is equivalent to spring broadcast ammonium nitrate when soil moisture conditions permit sufficiently early application.

In addition to the effects on yield, consistent increases in protein content of the wheat produced have been obtained from nitrogen treatments in recent experiments. This has applied as well in the western section of the state where winter wheat is produced after summer fallow. Spring treatments are noted to be superior to fall application, and ammonium nitrate more efficient than ammonium sulfate in this respect.

It is demonstrated that a direct relationship exists between nitrification rate of the soil and check yield of wheat and a negative correlation exists between nitrification rate and yield increases from nitrogen fertilization. These relationships are most valid when restricted to a limited range of soil and climatic conditions, but are found meaningful for all of the state where continuous cropping is practiced.

Best results from phosphorus fertilization of wheat occur when the fertilizer is placed with the seed in the soil. Broadcasting prior to final tillage is fairly satisfactory, but broadcasting just prior to or following drilling is not recommended. Consistent positive results with phosphate on wheat are presented for Sharpsburg and other soils of southeastern Nebraska, and calcareous sandy soils elsewhere, but little present need is apparent for supplements of this element for most of the major soil series investigated in central and western Nebraska.

Studies with different types of phosphorus carriers indicate that the various superphosphates and ammonium phosphates are superior to all other carriers investigated. Calcium metaphosphate and two TVA 'nitric phosphates' bear promise on acid soils, but are not adapted for limy soils. Rock phosphate and fused rock phosphate do not appear to be satisfactory phosphate carriers for use with the wheat crop in Nebraska. Nutrient solutions for supplying phosphorus by seed absorption have not proved promising in experiments conducted to date. Data obtained on rate of phosphorus application to winter wheat indicate that 20 to 30 pounds of available phosphorus as P_2O_5 per acre is adequate under most conditions.

The relationship between nitrogen and phosphorus is developed, showing that phosphorus fertilizer applied alone to soils deficient in both nitrogen and phosphorus is not likely to constitute profitable fertilizer practice. Under such circumstances both elements must be supplied. Further, a definite trend toward depression in yield is evidenced from application of phosphorus carriers alone to soil definitely deficient in nitrogen but not in phosphorus.

In diagnosing possible need for supplemental phosphorus, it is suggested that this need may be considered a foregone conclusion for extremely sandy and most calcareous soils. The usefulness of organic matter and pH values and a quick testing method for soluble phosphorus is shown for other soils. A definite negative correlation is reported for the 1948-1952 experiments between soluble phosphorus, as determined, and yield increases from phosphorus fertilization, i.e., where spring nitrogen was applied as well. Little relationship is apparent where the testing results are compared with the yield response from phosphorus fertilizer applied alone, since the latter treatment had little effect on yields at most locations.

Supplemental phosphorus has been found to be of little value for increasing the protein content of wheat in much of Nebraska. In fact, where applied to soils quite deficient in nitrogen but not deficient in phosphorus it has had an apparent depressing effect.

The summarized potassium fertilization results with wheat indicate little need for this element to date as fertilizer on the major Nebraska zonal soils devoted to wheat production. The laboratory determinations which were made confirm these field results in that all series portray large amounts of exchangeable potassium, ranging between 1.3 and 3.0 m.e./100 g. in the surface horizon. Even the lowest of these figures represents a very large amount of exchangeable potassium on an acre-foot basis. As with phosphorus, there appears to be no advantage in an application of supplemental potassium to soils not deficient in the element. On some occasions yield reductions as well as decreases in protein content of the grain may result. It is believed that potash fertilization of winter wheat is practical now only on a few sandy soil areas of the state.

There appears to be a place for mixed fertilizers containing nitrogen and phosphorus where both elements are deficient in the soil. Although there is only a small advantage on the average zonal soils of Nebraska for using mixed fertilizers over a fall application of phosphate plus a spring application of nitrogen fertilizer, the advantage is greater on soils markedly deficient in nitrogen.

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TABLE 28.—Moisture equivalent, pH, organic matter content, nitrification rate and available phosphorus in soils from different experimental sites from 1948-1952. (All determinations made on 0-8" samples except as noted.)

Field No.[1]	County	Soil class	Moisture equivalent, %	pH 0-8"	pH 10-20"	Organic matter, %	Initial nitrate, p.p.m. NO_3—N	Nitrification rate (4 weeks), p.p.m. NO_3—N	Soluble phosphorus,[2] p.p.m of P
				Sharpsburg soils					
1.	Dodge	Si.c.l.	27.4	6.0	6.0	3.85	2.3	15.2	0.30
2.	Dodge	Si.c.l.	28.6	5.6	5.8	3.40	8.9	20.5	......
3.	Cass	Si.c.l.	28.3	5.5	5.8	3.95	19.3	12.7	0.34
4.	Dodge	Si.c.l.	......	5.8	6.3	......	9.3	18.2	0.20
5.	Nemaha	Si.c.l.	27.5	5.6	5.7	......	6.3	26.2	0.14
6.	Richardson	Si.c.l.	26.7	5.8	6.2	4.83	5.1	38.6	0.17
7.	Dodge	Si.c.l.	......	5.9	6.2	3.77	0.5	35.0	0.15
8.	Nemaha	Si.c.l.	......	5.6	5.9	3.91	6.5	51.0	0.15
8a.	Lancaster	Si.c.l.	......	5.7	5.8	......	8.0	......	0.15
8b.	Dodge	Si.c.l.	......	5.5	5.8	3.36	8.5	22.0	0.21
	Mean		27.7	5.7[3]	5.8[3]	3.87	7.5	26.6	0.21
				Crete soils					
9.	Butler	Si.l.	23.6	5.6	6.0	3.15	4.3	15.1	......
10.	Seward	Si.c.l.	26.6	6.3	6.4	4.69[4]	5.8[4]	36.7[4]	0.50[4]
11.	Saline	Si.c.l.	27.1	5.4	5.5	2.99	7.5	10.0	0.39
12.	York	Si.l.	23.9	5.5	5.9	3.16	10.5	12.5	0.40
13.	Fillmore	Si.c.l.	25.0	5.7	6.3	2.82	3.7	14.4[5]	......
			(32.8)[7]			(2.11)	(0.0)	(4.4)	
14.	Fillmore	Si.l.	24.8	5.5	6.0	2.80	5.0	12.5	0.29
15.	Thayer	Si.c.l.	24.8	5.5	6.1	2.06	6.3	14.9[6]	......
			(33.3)			(1.51)	(2.0)	(1.1)	
16.	Clay	Si.l.	24.6	5.6	6.2	3.18[4]	16.8[4]	30.7[4]	......
17.	Nuckolls	Si.l.	23.0	5.6	6.0	2.37	9.2	13.9	0.39
18.	Adams	Si.l.	25.0	5.7	6.2	2.19	2.8	14.7	......

TABLE 28.—*Continued.*

Field No.[1]	County	Soil class	Moisture equivalent, %	pH 0-8″	pH 10-20″	Organic matter, %	Initial nitrate, p.p.m. NO_3—N	Nitrification rate (4 weeks), p.p.m. NO_3—N	Soluble phosphorus,[2] p.p.m of P
19.	Adams	Si.l.	22.4	6.1	6.2	1.90	4.8	15.8	0.33
20.	Clay	Si.l.	21.7	6.3	6.4	3.16	0.0	19.1	0.37
21.	Fillmore	Si.c.l.	26.4	6.3	6.5	3.17	0.9	22.5	0.34
22.	Clay	Si.l.	......	6.0	6.2	3.07	4.0	15.0	0.65
23.	Saline	Si.l.	......	5.8	5.9	3.49	2.0	19.5	0.18
23a.	Fillmore	Si.l.	......	5.9	6.6	2.65	5.5	18.5	0.26
23b.	Clay	Si.l.	......	5.6	6.4	2.68	21.3	20.0	0.44
	Mean (except fields 4 and 16)		24.5	5.8	6.2	2.78	5.9	16.0	0.37
				Hastings soils					
24.	Polk	Si.l.	24.1	5.7	6.0	3.33	4.8	14.6	0.37
25.	York	Si.c.l.	26.4	5.6	6.0	3.46	7.5	17.5	......
26.	Hamilton	Si.l.	24.4	6.0	6.3	2.69	12.8	14.0	......
27.	Hamilton	Si.l.	22.1	5.7	6.3	2.84	3.5	15.0	0.60
28.	Adams	Si.l.	23.5	5.7	6.2	1.95	7.8	19.7	0.33
29.	Kearney	Si.l.	23.6	6.5	6.7	1.38	6.0	9.6	0.15
30.	Kearney	Si.l.	24.8	6.5	6.6	2.23	8.5	12.7	0.36
31.	Phelps	Si.l.	24.7	6.0	6.7	2.05	9.0	16.6	0.40
32.	Adams	Si.l.	21.8	6.4	6.8	2.56	7.9	18.3	0.16
33.	Platte	Si.c.l.	26.0	5.9	6.2	3.76	0.3	33.0	0.16
34.	Webster	Si.l.	......	6.1	6.4	2.37	1.0	13.0	0.27
35.	Hamilton	Si.l.	......	6.0	6.4	2.51	0.5	22.0	0.21
35a.	Howard	Si.l.	......	6.3	6.7	2.23	2.5	18.0	0.30
35b.	Custer	Si.l.	......	5.9	6.8	2.30	12.0	13.0	0.36
	Mean		24.1	6.0	6.4	2.55	6.0	16.9	0.31

TABLE 28.—*Continued.*

Field No.[1]	County	Soil class	Moisture equivalent, %	pH 0-8″	pH 10-20″	Organic matter, %	Initial nitrate, p.p.m. NO_3—N	Nitrification rate (4 weeks), p.p.m. NO_3—N	Soluble phosphorus,[2] p.p.m of P
				Holdrege soils					
36.	Furnas	Si.l.	23.1	6.6	....	1.71	9.5	9.3	0.52
37.	Red Willow	Si.l.	24.6	7.0	8.0	1.55	9.3	13.9	0.43
38.	Frontier	Si.l.	19.9	6.5	6.9	2.25	15.1	18.1	1.2
39.	Gosper	Si.l.	23.1	6.7	7.1	2.56	17.1	24.4	0.29
40.	Phelps	Si.l.	......	6.3	6.8	2.93	20.0	19.0	1.56
41.	Hayes	Si.l.	......	6.7	7.4	2.37	4.0	16.5	0.54
42.	Chase	L.	......	6.7	7.6	1.95	13.0	12.0	0.68
43.	Chase	L.	......	6.7	7.3	1.82	2.5	15.0	0.54
44.	Red Willow	Si.l.	......	6.8	7.6	1.75	7.5	15.0	0.57
45.	Phelps	Si.l.	......	6.2	6.6	2.23	3.5	16.5	0.27
46.	Phelps	Si.l.	......	6.3	6.7	2.58	6.5	23.0	0.63
47.	Hitchcock	Si.l.	......	7.0	7.2	1.75	0.5	16.0	0.25
47a.	Frontier	Si.l.	......	7.6	7.2	2.25	12.5	17.0	0.44
47b.	Harlan	Si.l.	......	6.2	6.8	1.56	8.1	13.4	0.18
47c.	Hitchcock	Si.l.	......	6.5	7.3	2.01	11.9	17.1	0.26
	Mean		22.7	6.6	7.2	2.08	9.4	16.4	0.56
			Keith and Sherman soils						
48.	Cheyenne	Keith l.	22.2	6.5	6.7	2.45	3.5	10.9	......
49.	Cheyenne	Keith l.	21.4	6.4	6.7	1.77	29.0	6.0	0.60
50.	Sheridan	Keith si.l.	22.6	6.5	6.7	2.08	122.0	28.0	0.48
51.	Box Butte	Keith l.	22.8	6.3	6.6	1.86	0.3	20.9	......
52.	Dundy	Keith si.l.	22.8	6.7	7.5	2.24	26.0	6.5	0.37
53.	Lincoln	Keith l.	21.0	6.0	6.5	2.25	26.0	9.0	2.32
54.	Box Butte	Sherman l.	22.3	6.8	6.9	1.79	5.6	13.8	0.55
55.	Chase	Sherman si.l.	23.4	7.1	7.3	2.19	9.6	14.4	0.72
56.	Sheridan	Keith l.	23.2	8.0	8.2	1.96	16.4	26.4	0.28
57.	Morrill	Keith v.f.s.l.	......	6.7	7.7	2.02	18.5	34.0	0.54

TABLE 28.—*Continued.*

Field No.[1]	County	Soil class	Moisture equivalent, %	pH 0-8″	pH 10-20″	Organic matter, %	Initial nitrate, p.p.m. NO_3—N	Nitrification rate (4 weeks), p.p.m. NO_3—N	Soluble phosphorus,[2] p.p.m. of P
58.	Sheridan	Keith l.	......	7.1	7.4	2.65	9.5	35.5	0.87
59.	Sheridan	Keith l.	......	7.3	7.9	2.23	5.0	15.0	0.19
60.	Hitchcock	Keith l.	......	7.0	7.1	1.81	5.0	19.0	0.33
60a.	Cheyenne	Keith l.	......	6.3	7.4	2.16	11.9	19.6	0.38
60b.	Dundy	Keith l.	......	7.2	7.7	1.95	9.4	12.1	0.79
	Mean		22.4	6.8	7.2	2.09	19.8	18.1	0.65
			Rosebud soils						
61.	Box Butte	Rosebud sa.l.	15.6	7.6	8.0	2.03	12.5	17.5	0.33
62.	Cheyenne	Rosebud l.	22.2	7.9	8.5	2.22	21.0	26.8	0.28
63.	Kimball	Rosebud si.l.	......	8.2	8.2	......	27.5	11.0	0.16
64.	Box Butte	Rosebud sa.l.	12.1	7.0	....	1.33	......	11.3	0.65
	Mean		16.6	7.7	8.2	1.89	20.3	16.7	0.35
			Other soils						
65.	Perkins	Dunlap si.l.	22.2	5.8	5.9	1.84	55.0	40.0	0.79
66.	Kimball	Dunlap si.l.	21.0	7.5	7.2	2.75	20.0	29.5	0.81
67.	Kimball	Dunlap si.l	......	8.0	7.4	2.16	5.0	12.5	0.33
67a.	Perkins	Dunlap si.l	......	5.8	7.0	2.59	40.0	45.5	0.41
68.	Howard	Wann f.s.l.	17.6	8.3	7.3	2.53	0.7	15.6	0.20
69.	Colfax	Wann f.s.l.	18.4	8.1	8.2	2.55	28.8	33.6	0.15
70.	Colfax	Wann f.s.l.	......	8.4	8.6	3.14	2.0	31.5	0.15
70a.	Colfax	Wann f.s.l.	......	8.1	8.7	2.25	24.0	24.0	......
71.	Johnson	Carrington c.l.	24.3	5.6	5.6	......	6.5	15.5	0.14
72.	Pawnee	Carrington c.l.	......	5.6	6.3	2.23	1.0	15.0	0.11
73.	Johnson	Carrington si.c.l.	......	5.5	6.1	2.37	4.5	15.0	0.03

TABLE 28.—*Continued.*

Field No.[1]	County	Soil class	Moisture equivalent, %	pH		Organic matter, %	Initial nitrate, p.p.m. NO_3—N	Nitrification rate (4 weeks), p.p.m. NO_3—N	Soluble phosphorus,[2] p.p.m. of P
				0-8″	10-20″				
73a.	Seward	Carrington si.c.l.	......	6.1	6.3	2.18	3.0	23.0	0.17
73b.	Pawnee	Carrington si.c.l.	......	5.6	6.2	2.20	1.3	20.2	0.12
74.	Gage	Burchard si.c.l.	......	5.8	6.3	2.79	2.0	16.0	0.12
75.	Douglas	Marshall si.l.	......	5.9	6.2	2.65	1.0	14.5	0.11
76.	Lincoln	Anselmo sa.l.	......	6.5	6.7	1.19	0.5	10.0	0.60
77.	Hitchcock	Bridgeport sa.l.	......	7.1	7.7	0.77	1.5	14.5	0.30
77a.	Colfax	Moody si.l.	......	5.7	5.8	2.90	5.8	20.0	0.11

[1] See Table 30 for location of fields.
[2] Soluble phosphorus determined on extraction of 1.5 parts buffer solution to 1 part soil.
[3] Geometric means of pH values.
[4] Omitted in determination of mean for all samples.
[5] Nitrification rate of limed soil was 37.6 p.p.m.
[6] Nitrification rate of limed soil was 31.2 p.p.m.
[7] Values in parentheses from 10- to 20-inch depths.

TABLE 29.—Cation exchange capacity and exchangeable cations in soils from certain experimental sites, 1948-1952.

Field No.	County	Cation exchange capacity		Exchangeable bases in m.e./100 grams and per cent saturation[1]									
				Total		Calcium		Magnesium		Potassium		Sodium	
		0-8″	10-20″	0-8″	10-20″	0-8″	10-20″	0-8″	10-20″	0-8″	10-20″	0-8″	10-20″
						Sharpsburg soils							
1.	Dodge	22.8	24.5	21.5	22.9	15.0	15.2	5.0	6.5	1.4	1.0	0.1	0.2
				(94)	(94)	(66)	(62)	(22)	(26.5)	(6.0)	(4)	(0.4)	(0.8)
3.	Cass	27.8	36.0	21.1	28.5	14.9	20.5	4.7	7.0	1.4	0.9	0.1	0.13
				(76)	(79)	(54)	(57)	(17)	(19)	(5.0)	(2.5)	(0.4)	(0.4)
8a.	Lancaster	23.5	27.4	20.5	25.9	13.1	16.7	6.3	8.3	1.0	0.7	0.1	0.2
				(87)	(95)	(56)	(61)	(27)	(30)	(4.3)	(2.6)	(0.4)	(0.73)
	Mean	24.7	29.3	21.0	25.8	14.3	17.5	5.3	7.3	1.3	0.9	0.1	0.18
				(86)	(89)	(59)	(60)	(22)	(25)	(5.1)	(3.0)	(0.4)	(0.65)
						Crete soils							
12.	York	19.4	22.5	16.3	18.8	11.6	14.0	3.2	3.8	1.5	0.9	0.03	0.08
				(84)	(84)	(60)	(62)	(16)	(17)	(8)	(4)	(0.15)	(0.35)
13.	Fillmore	21.8	34.8	19.7	31.7	13.8	22.6	4.5	7.0	1.2	1.5	0.2	0.6
				(90)	(91)	(63)	(65)	(20)	(20)	(5.5)	(4.3)	(0.9)	(1.7)
16.	Clay	22.3	33.6	18.9	28.3	11.8	17.9	2.7	5.5	4.1	4.8	0.3	0.13
				(85)	(84)	(53)	(53)	(12)	(16)	(18)	(14)	(1.3)	(0.4)
18.	Adams	18.6	22.1	17.4	20.2	12.6	13.7	3.6	5.2	1.2	1.2	0.05	0.1
				(94)	(92)	(68)	(62)	(19)	(24)	(6.5)	(5.4)	(0.3)	(0.5)
19.	Adams	17.5	25.0	16.0	23.7	9.5	16.7	5.0	5.5	1.4	1.3	0.1	0.2
				(91)	(95)	(54)	(67)	(29)	(22)	(8)	(5.2)	(0.6)	(0.8)
	Mean (except Clay)	19.3	26.1[2]	17.4	23.6	11.9	16.7	4.1	5.4	1.3	1.2	0.10	0.25
				(89.5)	(90.5)	(61)	(64)	(21)	(21)	(7)	(4.7)	(0.49)	(0.84)

TABLE 29.—*Continued.*

Field No.	County	Cation exchange capacity		Exchangeable bases in m.e./100 grams and per cent saturation[1]									
				Total		Calcium		Magnesium		Potassium		Sodium	
		0-8″	10-20″	0-8″	10-20″	0-8″	10-20″	0-8″	10-20″	0-8″	10-20″	0-8″	10-20″
						Hastings soils							
25.	York	20.2	19.1	17.8	17.7	13.2	12.6	3.2	3.9	1.4	1.1	0.05	0.13
				(88)	(93)	(65)	(66)	(16)	(20)	(6.9)	(5.8)	(0.25)	(0.68)
26.	Hamilton	17.7	22.0	18.0	20.8	12.4	15.2	3.9	4.0	1.7	1.5	0.0	0.08
				(100)	(95)	(70)	(69)	(22)	(18)	(9.6)	(6.8)	(0.0)	(0.36)
27.	Hamilton	18.7	20.2	16.3	18.2	12.0	13.7	2.8	3.3	1.5	1.1	0.05	0.08
				(87)	(90)	(64)	(68)	(15)	(16)	(8.0)	(5.4)	(0.27)	(0.40)
29.	Kearney	19.3	23.7	18.1	26.1[3]	13.4	20.0[3]	2.9	4.5	1.2	1.4	0.57	0.16
				(94)	(100)	(69)	(74)	(15)	(19)	(6.2)	(5.9)	(3.0)	(0.67)
30.	Kearney	20.7	22.1	18.9	21.8	13.8	14.9	3.3	4.4	1.7	2.2	0.13	0.31
				(91)	(99)	(67)	(67)	(16)	(20)	(8.2)	(10.0)	(0.63)	(1.40)
	Mean	19.3	21.4	17.8	20.4	13.0	14.8	3.2	4.0	1.5	1.5	0.16	0.15
				(90)	(95)	(67)	(69)	(17)	(19)	(7.8)	(6.8)	(0.83)	(0.70)
						Holdrege soils							
36.	Furnas	18.5	......	17.0	......	11.5	......	3.9	....	1.5	....	0.08	......
				(91)	(....)	(62)	(....)	(21)	(....)	(8.1)	(....)	(0.43)	(......)
37.	Redwillow	20.1	26.5	23.0[3]	31.6[3]	16.8[3]	23.8[3]	4.5	6.5	1.7	1.2	0.03	0.10
				(100)	(100)	(69)	(71)	(22)	(25)	(8.5)	(4.5)	(0.15)	(0.38)
47a.	Frontier	18.5	20.5	16.3	20.0	11.0	14.2	3.6	4.5	1.5	1.1	0.16	0.17
				(88)	(98)	(59)	(69)	(19)	(22)	(8.1)	(5.4)	(0.86)	(0.83)
47b.	Harlan	16.4	23.6	15.5	21.6	9.8	13.8	4.3	6.4	1.2	1.1	0.15	0.30
				(95)	(92)	(60)	(68)	(26)	(27)	(7.3)	(4.7)	(0.91)	(1.27)
	Mean	18.4	23.5	16.3	20.8	12.3	14.0	4.1	5.8	1.5	1.1	0.10	0.19
				(94)	(97)	(63)	(69)	(22)	(25)	(8.0)	(4.9)	(0.59)	(0.83)

TABLE 29.—*Continued.*

Field No.	County	Cation exchange capacity		Exchangeable bases in m.e./100 grams and per cent saturation[1]									
				Total		Calcium		Magnesium		Potassium		Sodium	
		0-8″	10-20″	0-8″	10-20″	0-8″	10-20″	0-8″	10-20″	0-8″	10-20″	0-8″	10-20″
				Keith and Rosebud soils									
50.	Sheridan	18.5	26.0	27.1[3]	27.0[3]	19.1[3]	17.8[3]	5.3	7.0	2.6	2.1	0.10	0.10
				(100)	(100)	(57)	(65)	(29)	(27)	(14.0)	(8.1)	(0.54)	(0.38)
61.	Box Butte	16.5	14.5	23.9[3]	......[4]	21.4[3]	......[4]	1.2	2.0	1.3	1.0	0.00	0.00
				(100)	(100)	(85)	(79)	(7.3)	(14)	(7.9)	(6.9)	(0.00)	(0.00)
60a.	Cheyenne	17.3	21.0	14.9	21.2	9.7	13.8	3.4	5.1	1.6	2.1	0.16	0.17
				(86)	(100)	(56)	(66)	(20)	(24)	(9.2)	(10.0)	(0.92)	(0.81)
	Mean	17.4	20.5	......	......	......	......	3.3	4.7	1.8	1.7	0.08	0.09
				(95)	(100)	(66)	(70)	(19)	(22)	(10.4)	(8.3)	(0.49)	(0.40)

[1] Percentage saturation shown in parentheses.
[2] Mean value would likely be higher if the 10- to 20-inch depth represented the B horizon in all the fields.
[3] Slightly calcareous samples.
[4] Moderately calcareous samples.

TABLE 30.—Location, soil series classification and cropping practice of 1948-1952 fertilizer experimental sites for winter wheat.

Field No.	Year of test	Cooperator	County	Soil series	Cropping practice	Comments
1.	1948	F. Brandt	Dodge	Sharpsburg	Continuous	
2.	1949	E. Miller	Dodge	Sharpsburg	Continuous	Plot lost
3.	1949	H. Hunterman	Cass	Sharpsburg	Continuous	
4.	1950	E. Miller	Dodge	Sharpsburg	Continuous	
5.	1950	M. P. Ward	Nemaha	Sharpsburg	Continuous	
6.	1950	W. Heim	Richardson	Sharpsburg	Continuous	
7.	1951	L. Tank	Dodge	Sharpsburg	Continuous	
8.	1951	M. P. Ward	Nemaha	Sharpsburg	Continuous	
8a.	1952		Lancaster	Sharpsburg	Continuous	
8b.	1952	A. Buell	Dodge	Sharpsburg	Continuous	
9.	1949	L. Bongers	Butler	Crete	Continuous	Plot lost
10.	1948	D. Schultz	Seward	Crete	Continuous	
11.	1949	F. Rezny	Saline	Crete	Continuous	
12.	1948	Wagner	York	Crete	Continuous	
13.	1949	C. Gewacke	Fillmore	Crete	Continuous	
14.	1949	C. Newman	Fillmore	Crete	Continuous	Plot lost
15.	1949	J. Wiedel	Thayer	Crete	Continuous	
16.	1949	Van Spreckleson	Clay	Crete	Continuous	
17.	1949	J. Karmazin	Nuckolls	Crete	Continuous	
18.	1949	A. Gangwish	Adams	Crete	Continuous	Plot lost
19.	1948	A. Gangwish	Adams	Crete	Continuous	
20.	1950	G. Rader	Clay	Crete	Continuous	
21.	1950	C. Newman	Fillmore	Crete	Continuous	
22.	1951	L. Dana	Clay	Crete	Continuous	
23.	1951	F. Sefrna	Saline	Crete	Continuous	
23a.	1952	M. Lovegrove	Fillmore	Crete	Continuous	
23b.	1952	W. Yost	Clay	Crete	Continuous	
24.	1949	L. Lamoree	Polk	Hastings	Continuous	Plot lost
25.	1949	G. H. Finney	York	Hastings	Continuous	Plot lost
26.	1948	H. Beins	Hamilton	Hastings	Continuous	
27.	1948	H. Culbertson	Hamilton	Hastings	Continuous	
28.	1948	R. Daugherty	Adams	Hastings	Summer fallow	
29.	1948	M. Christensen	Kearney	Hastings	Continuous	
30.	1949	C. Borgaard	Kearney	Hastings	Continuous	
31.	1949	H. Urick	Phelps	Hastings	Continuous	
32.	1950	E. Borchers	Adams	Hastings	Continuous	
33.	1950	H. Folz	Platte	Hastings	Continuous	
34.	1951	G. Seeman	Webster	Hastings	Continuous	
35.	1951	D. Oswald	Hamilton	Hastings	Continuous	
35a.	1952	T. Tucker	Howard	Hastings	Continuous	
35b.	1952	A. Wedholm	Custer	Hastings	Summer fallow	
36.	1948	H. Garey	Furnas	Holdrege	Summer fallow	
37.	1949	B. Duckworth	Red Willow	Holdrege	Summer fallow	
38.	1950	H. Nickerson	Frontier	Holdrege	Summer fallow	
39.	1950	R. Schroeder	Gosper	Holdrege	Summer fallow	
40.	1951	D. Young	Phelps	Holdrege	Summer fallow	
41.	1951	Fair Grounds	Hayes	Holdrege	Continuous	
42.	1951	R. Luhrs	Chase	Holdrege	Summer fallow	
43.	1951	R. Luhrs	Chase	Holdrege	Continuous	
44.	1951	S. Quigley	Red Willow	Holdrege	Summer fallow	
45.	1951	H. Youngquist	Phelps	Holdrege	Continuous	
46.	1951	A. Fitch & Son	Phelps	Holdrege	Continuous	

TABLE 30.—*Continued.*

Field No.	Year of test	Cooperator	County	Soil series	Cropping practice	Comments
47.	1951	R. Roose	Hitchcock	Holdrege	Continuous	
47a.	1952	D. Swanson	Frontier	Holdrege	Summer fallow	
47b.	1952	D. Bantam	Harlan	Holdrege	Summer fallow	
47c.	1952	W. Richard	Hitchcock	Holdrege	Summer fallow	
48.	1949	T. Carlson	Cheyenne	Keith	Continuous	Plot lost
49.	1949	T. Carlson	Cheyenne	Keith	Summer fallow	
50.	1948	F. Shannon	Sheridan	Keith	Summer fallow	
51.	1949	C. Swanson	Box Butte	Keith	Summer fallow	
52.	1949	E. Keiser	Dundy	Keith	Summer fallow	Plot lost
53.	1949	C. Goedert	Lincoln	Keith	Summer fallow	
54.	1949	R. Stenberg	Box Butte	Sherman	Continuous	
55.	1950	H. Stock	Chase	Sherman	Summer fallow	(1)
56.	1950	R. Schmidt	Sheridan	Keith	Continuous (2)	
57.	1951	D. Kraeder	Morrill	Keith	Summer fallow	
58.	1951	A. Nelson	Sheridan	Keith	Summer fallow	
59.	1951	C. King	Sheridan	Keith	Summer fallow	
60.	1951	O. Miller	Hitchcock	Keith	Continuous	
60a.	1952	A. Westerhoff	Cheyenne	Keith	Summer fallow	
60b.	1952	H. Stock	Dundy	Keith	Summer fallow	
61.	1948	T. B. Kosmiscki	Box Butte	Rosebud	Summer fallow	
62.	1950	S. J. Flora	Cheyenne	Rosebud	Summer fallow	
63.	1950	R. Gunderson	Kimball	Rosebud	Summer fallow	
64.	1950	Alliance Sta.	Box Butte	Rosebud	Summer fallow	
65.	1949	Kimbel	Perkins	Dunlap	Summer fallow	
66.	1950	R. Gunderson	Kimball	Dunlap	Summer fallow	
67.	1951	R. Gunderson	Kimball	Dunlap	Summer fallow	
67a.	1952	G. Daughty	Perkins	Dunlap	Summer fallow	
68.	1949	G. Vlock	Howard	Wann	Continuous	
69.	1950	F. Horejsi	Colfax	Wann	Continuous	
70.	1951	F. Horejsi	Colfax	Wann	Continuous	
70a.	1952	C. Kluck	Colfax	Wann	Continuous	
71.	1950	W. Schuey	Johnson	Carrington	Continuous	
72.	1951	O. Beethe	Pawnee	Carrington	Continuous	
73.	1951	W. Schuey	Johnson	Carrington	Continuous	
73a.	1952	G. Van Andel	Seward	Carrington	Continuous	
73b.	1952	H.Sommerhalder	Pawnee	Carrington	Continuous	
74.	1951	C. Bartlett	Gage	Burchard	Continuous	
75.	1951	E. Witto	Douglas	Marshall	Continuous	
76.	1951	E. Heffner	Lincoln	Anselmo	Summer fallow	
77.	1951	C. Carlson	Hitchcock	Bridgeport	Continuous	
77a.	1952	B. Michales	Colfax	Moody	Continuous	
			No soil samples available			
78.	1948	J. Anderson	York	Crete	Continuous	Plot lost
79.	1948	G. Gewacke	Fillmore	Crete	Continuous	Plot lost
80.	1948	N. Ogden	Fillmore	Crete	Continuous	Plot lost
81.	1948	P. Mumdorf	Clay	Crete	Continuous	Plot lost
82.	1948	J. Karmazin	Nuckolls	Crete	Continuous	Plot lost
83.	1948	C. Seeman	Webster	Crete	Continuous	Plot lost
84.	1948	H. Swanson	Kearney	Crete	Continuous	Plot lost
85.	1948	A. Hablitzel	Frontier	Holdrege	Summer fallow	

TABLE 30.—*Continued.*

Field No.	Year of test	Cooperator	County	Soil series	Cropping practice	Comments
86.	1948	N. McNutt	Hayes	Holdrege	Summer fallow	
87.	1948	W. Pollman	Hitchcock	Holdrege	Summer fallow	
88.	1948	J. Keiser	Dundy	Keith	Summer fallow	
89.	1948	I. Widger	Chase	Keith	Summer fallow	
90.	1948	M. Keuten	Perkins	Dunlap	Summer fallow	Extreme drouth
91.	1948	E. Anderson	Cheyenne	Rosebud	Summer fallow	
92.	1948	W. Kelso	Kimball	Keith	Summer fallow	Plot lost
93.	1948	W. Riis	Box Butte	Keith	Summer fallow	Plot lost
94.	1949	Henske	Jefferson	Crete	Continuous	
95.	1949	L. Hohlen	Adams	Hastings	Continuous	
96.	1949	H. Beins	Hamilton	Hastings	Continuous	
97.	1948	Exp. Sta. Farm	Lancaster	Sharpsburg	Continuous	
98.	1948	C. R. Tyrrel	Lancaster	Waukesha	Continuous	
99.	1950	O. Broecker	Harlan			

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